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(B denotes a Book Review)

ELIMINATION OF DUST FROM THE LUNGS AND THE INFLUENCE OF THE RETICULOENDOTHELIAL SYSTEM

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THE defence of the organism against inhaled dust operates either with the aim of preventing the inhalation of dust or of eliminating it from the alveoli and the bronchial tree. The phagocytosis of dust particles is a part of this complicated defensive mechanism. This problem is discussed in more detail in another place (FERIN and ÚLEHLOVÁ, 1958b).

The phagocytosis of dust is a fact which has been well known for a long time. There is however no unity in considering the significance of phagocytosis in the process of self-clearance. There have been assumptions that phagocytosis retains the dust in the lungs. An opposite conception is found in the work of MOTTURA (1958) and SCHILLER (1956) who declare that only those particles which have not been phagocytosed in the alveoli penetrate into the interstitium of the lungs. The most widely accepted conception is that the dust particles which have not been phagocytosed in the alveoli pass into the interstitium of the lungs. It is supposed, however, that these dust particles can no longer be eliminated.

Dust particles which have been phagocytosed in the alveoli can be transferred to the pharynx by the ciliated epithelium of the bronchial tree. The manner in which the dust-containing cells from the alveoli are transported to the bronchiolus respiratorious, which has no cilia, and thence up to the first ciliated cells is not clear yet. Aspiration, movement of the mucus from the alveoli into the bronchioles and the motility of the individual dust cells may each play a role.

As stated in another work (FERIN and ÚLEHLOVÁ, 1958c) the adrenocorticotropic hormone in a certain (small) dose promotes the elimination of dust from the lungs. Although we could not prove the mechanism of this effect, it was supposed that the increased rate of elimination of dust was elicited by an encouraging effect of ACTH on the function of the phagocytes. Contrary to the generally well-known inhibitory influence upon phagocytosis of ACTH, its administration under certain conditions—according to our conception in small doses—can encourage phagocytosis, as we documented, by data from scientific literature, in our above-mentioned paper. We proved this conception of the effect of small doses of ACTH on phagocytosis successfully in our later paper (FERIN *et al.*, 1960).

Following up these results we decided to study the correlation of the phagocyte-producing ability of the reticuloendothelial system (RES) with the elimination of dust from the lungs.

We set the following questions:

1. Has exposure to dust a general effect on the phagocyte-producing function of the RES?

2. Is there any correlation between the phagocyte-producing function of the RES
   and the rate of dust-elimination of the lungs?
3. Can the elimination of dust be influenced by the stimulation of the RES?

METHODS

Exposure to dust

A single intratracheal injection of dust (30 mg per rat) was administered by a
method suitable for quantitative experiments (FERIN and ÚLEHLOVÁ, 1958a).
Silica dust (97·6 per cent SiO_2) with a large fraction of particles about $1·5\,\mu$ in size
was used.

Determination of elimination of the dust from the lungs

A similar procedure to that employed in previous work was adopted (FERIN
and ÚLEHLOVÁ, 1958a, b, c). In 17, 27 and 70 days after injection of dust the
amount of SiO_2 in the lungs of the rats was determined by a gravimetrical method
(FERIN and ÚLEHLOVÁ, 1958a). The decrease of the amount of dust indicates the
elimination from the lungs over the period of 70 days.

Determination of the functional state of the RES

The method chosen followed that of TÖRÖ et al. (1951) with a modification
as to the evaluation. A detailed description is to be found in the work of FERIN
et al. (1960). This method is based on the chemical determination of silver in the
rat's liver two hours after intravenous administration of a known dose of colloidal
silver (Collargol). At a higher adsorptive capability of the RES a greater amount
of silver is held up in the liver. This in vivo method has the advantage of permitting
quantitative determination.

Experimental arrangement

After injection of dust determinations of the elimination of dust and of the
adsorptive function of the RES were carried out simultaneously. The correlation
between the elimination of dust from the lungs and the adsorptive function of the
RES was determined. In a further experiment the RES was stimulated by a sub-
cutaneous injection of $\frac{1}{2}$ per cent solution of trypan blue and the effect of this
on the elimination of dust from the lungs was followed.

RESULTS

After an intratracheal injection of 30 mg of dust per rat the following amounts
relative to the originally administered dust were found in otherwise uninfluenced
animals:

17th day after injection of dust 91 per cent
27th ,,   ,,   ,,   ,, ,, 69 ,, ,,
70th ,,   ,,   ,,   ,, ,, 62 ,, ,, .

These results are in conformity with our previous reports, as well as with the
data of NAGELSCHMIDT et al. (1957).

On the 27th day after exposure to dust the functional state of the RES was
unchanged in comparison with the control-group to which a physiological salt

solution had been administered intratracheally. A significant average increase of the adsorptive function of the RES in exposed rats amounting to 15 per cent maximal was found on the 70th day after injection of dust (Table 1).

TABLE 1. ADSORPTIVE FUNCTION OF THE RETICULOENDOTHELIAL SYSTEM AFTER DUST EXPOSURE OF RATS

Time after dust exposure (days)	Number of rats	Held-up Ag from administered amount (per cent)*		Significance of difference
		Control group	Experimental group	
27	19	76·6±4·8	73·8±4·2	—
70	17	72·3±9·1	83·9±3·3	P<0·01

*Average values ± standard deviation.

We wanted to know whether there was any correlation between the rate of elimination of the dust and the functional state of the RES in individual animals. On the 27th day after injection we found in dust-exposed rats a positive correlation between the elimination of the dust from the lungs and the activity of the RES. Rats with a higher adsorptive capability of the RES (greater amount of silver
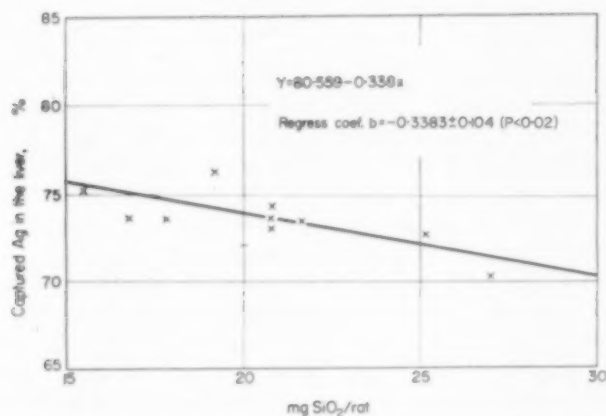
FIG. 1. The correlation between the adsorptive function of the RES and the dust remaining in the lungs after 17 days post dusting.

in the liver) had a higher eliminative capability of the lungs (less dust in the lungs). The regression coefficient $b = 0·3383 ± 0·104$. The deviation from zero is significant with probability of P<0·02 (Fig. 1). At the examination on the 70th day after injection of dust we found a greater dispersion of values and we were not able to confirm this finding.

In the next experiment we mobilized the RES by a sub-cutaneous injection of trypan blue a few days before the injection of dust. We used a ½ per cent physiological salt solution in doses of 0·5 ml/100 g of weight. A physiological salt solution was administered to the control-group. The injection of trypan blue was administered (once daily) once, twice and three times respectively to the experimental

animals. The exposure of the animals to dust was carried out on the third day following the last injection. The animals of the control-group eliminated 2·7 mg of dust from the originally administered amount of dust (30·3 mg per rat) within 17 days. The animals with mobilized RES eliminated as much as 9·1 mg per rat within the same period, i.e. 337 per cent in comparison with the control-group. Significance of difference P < 0·01 (Table 2). However we did not note any essential difference in the three experimental groups. The highest elimination (statistically insignificant) was found in the group which received only a single injection.

TABLE 2. INFLUENCE OF SOLUTION OF TRYPAN BLUE ON THE ELIMINATION OF DUST FROM THE LUNGS. 17 DAYS AFTER INTRATRACHEAL INJECTION OF $30·8 \pm 2·5$ mg SiO_2 PER RAT

Group	Number of rats	SiO_2 mg per rat in lungs*	Per cent from administered amount	SiO_2 per rat eliminated
Control	6	$28·1 \pm 2·5$	91	2·7
after 1 inj.	6	$21·7 \pm 2·8$	71	9·1
after 2 inj.	5	$22·4 \pm 1·1$	73	8·4
after 3 inj.	7	$23·1 \pm 3·7$	75	7·7

The difference from the control-group is in any case significant with probability of $P < 0·01$.* Average values $\pm$ standard deviations are cited.

CONCLUSIONS

According to our results we maintain the opinion that the functional state of the RES affects the elimination of dust from the lungs and furthermore that under favourable conditions it may affect it positively. A suitable preparation of the RES can raise considerably the effect on the eliminative mechanism. On the whole, we imagine that some of the "resting cells" of the defensive system are brought by the preceding moderate irritation into such a state that phagocytosis of the dust begins in a shorter time after an injection of dust, so that a greater amount of dust is phagocyted and eliminated. It appears from the literature that about 40 per cent of dust is eliminated within the first two months after a single intratracheal injection of 50 mg of dust per rat. After this the amount of dust in the lungs remains almost unchanged. The elimination is at a minimum. It is obvious that either dust which has not been removed within two months must have penetrated into the interstitium, whence its elimination by way of the bronchial tree is impossible, or the dust has become fixed in the lungs in some other way. It may be that either there a dust focus is formed or the motility of the dust cells towards the bronchial tree is stopped by changes in the bronchiolus respiratorius. A rapid elimination of dust during the early post-exposure phase, before the dust can become fixed in the lungs, is therefore of great importance. We suppose that a suitable stimulation of the RES is consequently very important. In our opinion it is not only a question of accelerating the elimination of dust during the first few days, but also the total diminution of the dust contents of the lungs.

All these observations lead to the idea that the often described favourable influence on dust changes in the lungs which is obtained by adding certain substances to the silica dust can, amongst other things, be due to the influencing of the functional state of the RES.

SUMMARY

After a single intratracheal injection of silica dust the elimination of the dust from the lungs of rats was determined up to the 70th day, and at the same time the adsorptive function of the RES was measured by Törö's method. The functional state of the RES on the 27th day was unchanged in comparison with a control-group. On the 70th day a significant rise in the adsorptive function of the RES was noted in dust-exposed animals. On the 27th day a positive correlation between the elimination of dust from the lungs and the activity of the RES was found in exposed rats. Those with a higher adsorptive function of the RES has less dust in the lungs.

In a further experiment stimulation of the RES was carried out by subcutaneous injection of trypan blue a few days before the animals were exposed to dust. These animals eliminated in 17 days 337 per cent as much dust as the animals in the control group.

According to these results one may suppose that the functional state of the RES is closely connected with the elimination of dust from the lungs. We think that the investigation of the clearing mechanism of the lungs and attempts to influence this mechanism must take the RES into consideration.

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SOME ASPECTS OF NASAL FUNCTION AND DYSFUNCTION IN RELATION TO ENVIRONMENTAL AIR

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INTRODUCTION

THE biological effects of air-conditioning was the original theme suggested for this paper. The term "biological effects" would, however, involve a discussion of too wide a field, and it is difficult to divorce the effects of air-conditioning from those of climatic conditions in general. I have therefore chosen to discuss some aspects of nasal function and dysfunction in relation to environmental air.

STRUCTURE OF NOSE AND PARANASAL SINUSES

For those who are not biologists, I shall mention very briefly the structure and function of the nose. The cavity of the nose as a whole is divided by a mid-line partition. The length of each separate cavity is about 6 cm and the height about 5 cm. The width is narrower nearer the roof (1–2 mm) but wider (about 1 cm) near the floor. Three longitudinal elevations, termed conchae or turbinates, are present on the lateral (i.e. outer) wall of each nasal cavity. Meatus is the name given to the depressions between these conchae and it is into these meatuses that air spaces in the bones surrounding the nose open. These air spaces are known as the paranasal sinuses. Those termed maxillary, ethmoidal and frontal are shown in this X-ray (Fig. 1). At the posterior end of the septum, the two nasal cavities merge into the post-nasal space which is coupled to the lower respiratory tract by the pharynx, a channel which is common to both the digestive tract and the respiratory tract.

With the exception of the roof, where the organ of smell is located, the nasal cavities are lined by ciliated mucous epithelium. As its name implies, this is a lining whose surface cells have permanent projections, termed cilia, which are $5–10 \mu$ long and about 0.2μ diameter (FAWCETT and PORTER, 1954). Each cell, which is about 5μ diameter has about 150–200 cilia (FAWCETT, 1954). The mucous blanket covering the cells is about 5μ thick (DALHAMN, 1956). The lining of the paranasal sinuses is thinner, contains fewer ciliated cells and more goblet cells than the lining of the nasal fossae.

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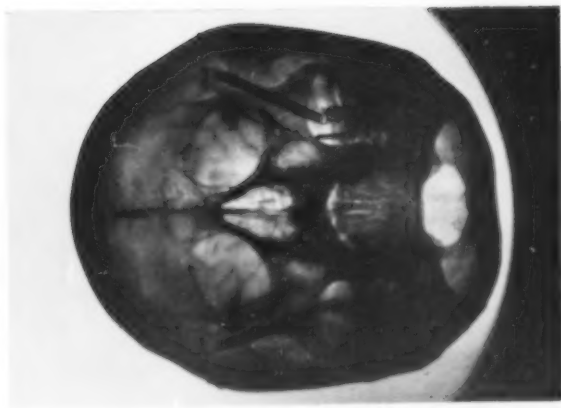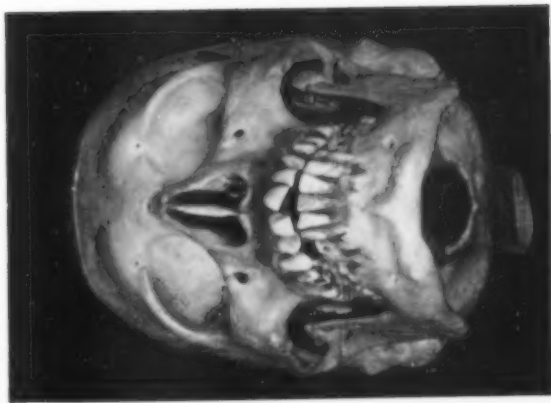
FIG. 1a and 1b. Photograph of skull demonstrated and X-ray of this skull showing paranasal sinuses.

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FUNCTIONS OF THE NOSE AND PARANASAL SINUSES

These are tabulated in Table 1.

TABLE 1. FUNCTIONS OF NOSE

1. Respiratory portal and a component part of respiratory airway.
2. Air-conditioning (MAGENDIE, 1929), i.e. humidification and warming of inspired air.
   Possibly, primarily to aid olfaction (NEGUS, 1954).
   Nose acts as a heat-and-moisture exchange apparatus, recovering heat and moisture from expired air (GOODALE, 1896; SEELEY, 1940; COLE, 1953).
3. Air purification.
   (a) Grosser filtration by vibrissae.
   (b) Deposition of particles by impingement—principal process (DAVIES, 1949; PATTLE, 1960).
   (c) Absorption of soluble gases by nasal mucous membrane (DAVIES, 1946; PATTLE, 1960).
   (d) Electrostatic precipitation (PROETZ, 1932).
   (e) Removal of particles by Muco-Ciliary Blanket (PROETZ, 1941).
   (f) Antibacterial action of Lysozyme (FLEMING, 1928).
   (g) Antigen-antibody reactions.
4. Protective reflexes—Sneezing.
5. Olfaction—the distance chemical sense. The prime function of the nose.
6. Phonation—Vocal Resonance. Production of nasal consonants /m/, /n/ and /ng/.
7. Heat Regulation (JACQUOT and MAYER, 1925; SCOTT, 1954; COLE, 1954b).

FUNCTIONS OF PARANASAL SINUSES

Unwanted air spaces following regression of olfactory sense in man (NEGUS, 1957).

The nasal airway forms less than one-fifth of the length of the respiratory channel, but it forms the greater part of the total airway resistance (BUTLER, 1960; DUBOIS et al., 1956). Excluding the nose, the mean airway resistance is $1 \cdot 5$ cm $H_2O/1/sec$ (DUBOIS et al., 1956), whilst the median normal nasal airflow resistance has been found to be $2 \cdot 5$ cm $H_2O/1/sec$ (STOKSTED, 1956). In a recent study, BUTLER (1960) found that nasal resistance averaged one and a half times the resistance of the lower airway. His data also showed that, for five normal subjects, the median rate of frictional (non-elastic) work of breathing was $0 \cdot 6$ kg M/min when breathing through the nose, but only $0 \cdot 1$ kg M/min when breathing through the mouth. Appreciable increase, or absence, of nasal resistance to inspiration is said to have a deleterious effect on the pump action of the circulation (NEGUS, 1929). Physiological changes in nasal air flow resistance due to changes in the thickness of the mucosa at the nose may occur as a result of:

(1) the changing demands of air-conditioning* and thermo-regulation;

(2) the physiologic nasal cycle (HEETDERKS, 1927; KAYSER, 1895; LILLIE, 1923; STOKSTED, 1952);

(3) the pulmonary-nasal reflex (ŠERCER, 1930)
and
(4) emotional (O'NEILL and MALCOLMSON, 1954; WOLFF et al., 1949) and endocrine (CONE, 1933) factors.

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* But see later remarks about physical basis of air-conditioning.

The nasal mucous membrane has an extensive vascular network (SWINDLE, 1935; 1937) whose capillaries drain into erectile venous sinusoids (HARPER, 1947), the efferent vessels of which have well-defined sphincters (LUCAS, 1952). Moreover, arteriovenous anastomoses can by-pass the superficial network (DAWES and PRITCHARD, 1953). Because of this erectile cavernous tissue and the pre-eminent vaso-motor sensitivity of the nose (MARTIN and MENDENHALL, 1915; MENDENHALL, 1915), considerable changes in the engorgement of the mucous membrane and consequently in the airflow resistance of the nose can occur.

KAYSER (1895) first mentioned the physiologic cycle in which the nose shows an alternating variation of its patency, the cycle of which averages about $2\frac{1}{2}$ hr (HEETDERKS, 1927). The cycles in the two nasal cavities are 180° out of phase (LILLIE, 1923). This cycle probably has a function in the secretion of nasal mucus (LILLIE, 1923).

ŠERCER (1930) described a reflex in which, when the body was horizontal, the lower lung produced an increase in the ipsilateral nasal airway resistance.

Emotional states characterized by increase in the sympathetic airflow produce a decrease in nasal airway resistance (O'NEILL and MALCOLMSON, 1954; WOLFF et al., 1949).

DOITEAU (1956) has shown experimentally on dogs that complete renewal of air occurs in 8 min (maxillary sinus) to 16 min (frontal sinus). Under normal conditions, only expired air reaches the openings (i.e. ostia) of the sinuses (PROETZ, 1941).

The degree of humidification and warming of inspired air depends upon:

(1) the humidity of the environmental air;
(2) the temperature of the environmental air;
(3) ventilation rate.

Under Arctic conditions, the water content of inspiratory pharyngeal air is about 75 per cent of that required to saturate lung air. Under tropical conditions, the water content varies between 80 per cent and 100 per cent of lung air water content, depending upon the humidity of the environmental air. The temperature of inspiratory pharyngeal air under Arctic conditions is about 31 °C, whilst that under tropical conditions varies between 34° and 37 °C (COLE, 1953b). Maximum ventilation lowers the inspiratory air temperature 3–4 °C in the pharynx and trachea (COLE, 1954a). The remainder of the respiratory tract brings the inspiratory air up to equilibration with physiological solutions.

GOODALE (1896) and SEELEY (1940) have stated that expiratory air cools and becomes drier as it passes through the nose. COLE (1953b) found that the heat recovery is remarkably constant, constituting between 30 per cent and 40 per cent of the heat transferred by the body to inspiratory air. The efficiency of this recovery process is greater at lower environmental air temperatures, as is also the efficiency of the water recovery process. As a percentage of water transferred to inspiratory air as it passes into the lungs, the recovery of water varies between 50 per cent and 25 per cent, depending upon whether we have an Arctic or a tropical climate. Assuming an average ventilation rate of 10 l/min, this will result in a water loss of about 300 ml/24 hr in Arctic conditions and a loss of from zero to 500 ml/24 hr under tropical conditions, depending upon the humidity. With the same ventilation rate, there will be a heat loss of about 400 kcal/24 hr under Arctic

conditions and anything up to 200 kcal/24 hr under tropical conditions, depending upon the humidity (COLE, 1953b).

Additional nasal fluid loss occurs because of swallowing of the mucous blanket which ciliary activity has propelled into the pharynx. The mucous blanket, formed principally by glandular secretion (INGELSTEDT and IVSTAN, 1954; MESSERKLINGER, 1950), is said to be renewed 2–4 times per hr (HILDING, 1949), and to entail a gross nasal fluid loss of about 1 l. in 24 hr (SLOME, 1952).

On grounds of comparative anatomy, SCOTT (1954) considered that the conchae (turbinates) are not essential to the air conditioning function of the nose. Moreover, in man, where there is a very simple turbinate system, air conditioning occurs with great readiness under all environmental air conditions (COLE, 1953b). Furthermore, COLE (1953a) demonstrated that a glass tube, containing moist blotting-paper, conditions respiratory air as effectively as the highly vascular mucosa of the upper respiratory tract.   ALLANDER has constructed a heat-and-moisture exchanger (H.M.E.) for use where a tracheotomy has been performed and which, therefore, can functionally be considered to be an artificial nose, analogous to the artificial kidney (KOCH et al., 1958). The apparatus consists of five 2·5 mm calibre, 10 cm long, stainless steel tubes enclosed in a plexiglass cylinder. The absolute humidity of inspired air is increased from 7 to 29 g/m³ after passing through the apparatus and the moisture recovery efficiency is 61 per cent.

Nasal filtration of airborne particles is primarily by impingement, i.e. inertia deposition (DAVIES, 1946; BOYLAND et al., 1947), so that, for particles of unit density, 80 per cent with a diameter of 12 μ are retained by the nose, but only 20 per cent with a diameter of 2 μ (LANDAHL and BLACK, 1947; LANDAHL and TRACEWELL, 1949; DAVIES, 1949; MAY, 1945) pointed out that the impactability of a particle is proportional to the square of its diameter and to its velocity. In a recent work on the retention of particles and gases in the human nose, PATTLE (1960) plotted his results and showed that for monodisperse clouds (i.e. clouds of uniform particle size) all points lay in a narrow band on either side of a line expressed by the equation:

$$P = 95 \left(1 - 0.5 \log \frac{D^2 W}{20 \cdot 2}\right)$$

where P = per cent penetration of nose
D = diameter in μ.
W = flow rate in l/min.

There was no obvious misalignment of the data. For polydisperse clouds, however, the nasal penetration was constant at about 80 per cent when the mass median diameter was 0·4 μ or less. There was no particular drift with particle size or flow rate.

DAVIES (1946) pointed out, and PATTLE (1960) confirmed, that gases will be completely removed by the nose provided that they are sufficiently soluble not to re-enter the air stream after colliding with the walls. However, the nose would not protect the lungs during prolonged exposure to a soluble gas.   Eventually, a balance will be reached between absorption of gas by the nasal mucous membranes and its removal by diffusion into the blood or tissues, or by its decomposition.

Electrostatic precipitation may be a factor in the filtration of biological particles. Airborne fungal spores are electrically charged (BULLER, 1909) and these charges

are already present when the spores are shed (GREGORY, 1957). However, because of their size, spores should be almost completely filtered in the nose by impaction.

LEHMANN (1935) claimed that people with dust disease of the lung had less efficient nasal filtration than normals.

Particles that have been deposited on the walls of the nose are transported by the muco-ciliary blanket to the pharynx where they are swallowed and destroyed in, or pass out through, the gastro-intestinal tract.

The unity of the respiratory tract as a whole is demonstrated by both the sneezing reflex and the vago-trigeminal (Brodie–Dickson) reflex. The latter reflex connotes stimulation of the posterior third of the nose which results in bronchospasm.

In discussing air-conditioning we are apt to forget that the prime function of the nose is olfaction. Efficient operation of this sense is dependent upon a high humidity of the air presenting the organoleptic compound to the chemo-receptor (BACKMANN, 1917-18; DURAND, 1918; PARKER, 1922). Consequently, NEGUS (1958) considered that the development of the air-conditioning ability by the nose was primarily to subserve the olfactory function. The keenest scented species have the most efficient air-conditioning apparatus (NEGUS, 1954). When the nose is by-passed, as by mouth-breathing, tracheostomy or laryngectomy, conditioning of the air before it reaches the alveoli still occurs, but with an increasing air-conditioning load on the lower respiratory tract.

The nose plays a secondary role in phonetics by producing the nasal consonants by means of coupling the nasal cavity to the coval tract during vowel production. Although the acoustic correlates of nasalization are not so clear (HOCKETT, 1955), information has recently been provided on some aspects of the nasalization of vowels by the use of a nasal analogue coupled to an electrical vocal tract analogue (HOUSE, 1957; HOUSE and STEVENS, 1956; ROSEN, 1958; STEVENS et al., 1953).

From studies in comparative anatomy, SCOTT (1954) showed that maxillary turbinate complexity is inversely related to the effectiveness of other available mechanisms of heat regulation. In man, heating or cooling stimuli to the body raise or lower the temperature of inspiratory air in the pharynx and expiratory air at the nostrils of a subject breathing air of constant conditions (COLE, 1954b). The submucosal turbinate temperature response to skin heating or cooling parallels the finger temperature response, but the temperature change is appreciably less (about ± 1 °C in the turbinate compared with ± 6 °C on the finger) (COLE, 1954b). Moreover, the temperature response of the respiratory nasal mucosa of the dog to remote thermal stimuli is much greater than in man (COLE, 1954b; VERZÁR et al., 1953). This suggests that the thermo-regulatory function of the nasal mucosa is probably vestigial in man where the skin is the dominant thermo-regulatory organ. Thermo-regulation is less easily achieved through the well-insulated skin surface of the dog. Incidentally, contrary to popular belief, the dog does possess sweat glands, as well as the well-known thermo-regulatory panting mechanism.

NASAL DYSFUNCTIONS RELATED TO ENVIRONMENTAL AIR CONDITIONS: THE PRESENT STATE OF KNOWLEDGE

Nasal diseases and dysfunctions that are stated to be related to environmental air conditions are tabulated in Table 2.

"Cold shock" is the term given to the sensation experienced on entering an

TABLE 2. NASAL DYSFUNCTIONS AND DISEASES STATED TO BE RELATED TO ENVIRONMENTAL
AIR CONDITIONS

1. "Air-conditioning shock" (YAGLOU, 1937; McCORD, 1941). Sensation experienced
   on sudden change of thermal environment. Nasal symptoms are, however, a
   secondary feature.

2. "Stuffy Nose" (BEDFORD, 1950). Due to steep temperature gradients between head
   and neck.

3. Post-nasal drip (TOLCZYNSKI, 1956). Awareness of otherwise normal flow of nasal
   mucous blanket in warm, dry atmospheres.

4. Tropical Vasomotor Nasal Disease (KING, 1949; MANSON-BAHR, 1956). Due to
   sensitivity of nasal mucous membrane to dust and thermal stimuli. Especially in
   allergic individuals. Probably nasal counterpart to "hot" air-conditioning
   "shock."

5. Acute Non-suppurative Sinusitis (MANSON-BAHR, 1956). As in rarefied, dry heat of
   Bauchi Plateau of Northern Nigeria. Probably related to 4.

6. Chronic Sinusitis. Increased prevalence in hot, dry, dusty atmospheres, e.g.
   Kenya (CHARTERS, 1951); Queensland (SHANKS and KEPLEY, 1957); S. Africa
   (WEINBREN, 1959).

air-conditioned room of lower temperature from hot outside atmosphere (YAGLOU,
1937). A similar uncomfortable feeling is produced by the opposite change. Both
biological effects are termed "air-conditioning shock" (McCORD, 1941) and when
it occurs the difference between the two temperature levels is often about 20 °F
(KINKADE, 1954). The rapid transition from one environmental temperature level
to another is considered to impose a strain on the thermo-regulatory mechanism,
with particular respect to the skin and the nasal mucosal vascular responses.
"Shock" is not a suitable word to use in this context, since circulatory collapse
does not occur. Subjects with a tendency towards nasal allergy or vasomotor
nasal disease are said to be less able to adjust quickly and to show an increased
susceptibility to upper respiratory tract infections.

To mitigate air-conditioning shock some buildings provide for gradual temper-
ature change by keeping halls and corridors at an intermediate temperature.
Another method of obviating air-conditioning shock is to limit the difference
between outside and inside dry-bulb temperature, to 5 °F if possible, and to
produce body comfort by changes in air humidity. Of course, this is not possible
under all climatic conditions, for example in hot dry climates.

Incorrect heating of a room may give greater warmth about the head than
near the floor. Such a temperature gradient between the feet and head may produce
chilling of the legs but a feeling of a stuffy, congested nose (BEDFORD, 1950).

Inadequate humidification of inspired air may be a prominent factor in the
etiology of post-nasal drip which is reported to be common in communities who
live and work under conditions of central heating (TOLCZYNSKI, 1956).

A vasomotor rhinitis is especially common in peoples migrating periodically
from the cool highlands of the tropics to the torrid sunbaked plains (MANSON–
BAHR, 1956). It was known to the Aztecs and was subsequently described by ZAGERS
in Java. Change of climate appears to be an important etiologic factor. KING
(1949) has also described a vasomotor rhinitis that is common amongst white
Service personnel in the Middle East. The incidence is greatest when the climate
is hottest, so that a thermal stimulus is considered to be the causative factor,
although many patients ascribed their condition to dust. Headache was present
in 35 per cent and there were radiological changes in the sinuses in 40 per cent

of this group. However, infection in the sinuses was demonstrable in only 2 per cent and nasal polyps were present in only 1 per cent, so it would seem that the condition was attributable to vasomotor changes frequently producing sinus block of the type described by SLUDER. This is probably similar to the acute sinusitis observed in hot dry rarefied climates (MANSON–BAHR, 1956). It is interesting to note that many of these patients stated that they suffered from "hay fever" whilst in temperate climates, but were free of it whilst in the Middle East. The sparsity of vegetation in their immediate environments was against the nasal condition in the Middle East being due to pollens.

In hot, wet, tropical climates, the vegetation is almost always in constant polination, so that there is a super-abundance of pollen in the atmosphere. Consequently, nasal allergy will be common in these areas (MANSON–BAHR, 1956). Sinusitis is, however, stated to be rare in these climates (JAFFÉ, 1951; MANSON–BAHR, 1956).

THORBURN (1957) showed that at an Air Force base in Southern Rhodesia, the prevalence of sinusitis shows a correlation coefficient of $+0.57$ when compared with the mean minimum temperature of the previous month. (For the 95 per cent significance level, $r = 0.576$.)   For the same population the prevalence of acute tonsillitis showed an inverse correlation with the absolute humidity in the previous month ($r = -0.61$). The altitude of the base was 4500 ft and for six months of the year the mean absolute humidity was 6.5 g/m^3 or less. It is a clinical impression that chronic sinusitis is more prevalent in hot, dry, dusty climates. In hot, wet, tropical climates, however, there is no greater prevalence than in temperate climates. For a period of over 60 years, the prevalence of respiratory disease in the personnel of the Royal Naval East Indies Squadron did not show any appreciable difference from that in personnel of the Home Fleet (COLLINS, 1955).

METHODS OF INVESTIGATING NOSE-ENVIRONMENTAL AIR RELATIONSHIPS

These can be grouped into three main categories:

(1) Animal experiments.
(2) Human physiological experiments: the climatic room.
and (3) Epidemiological investigations:
     (a) in respect of air-conditioning,
and (b) in respect of different climatic areas.

Animal experiments

Since so much can now be done in the way of human physiological experiments, less animal experiments need be performed and so less data need be extrapolated from animals to man. There are still some functions, however, that can only be satisfactorily studied on animal preparations. In the subject under consideration, this statement applies to studies on the activity of the muco-ciliary blanket.

PROETZ (1933) reported that cilia were quickly affected by drying, and it has been suggested (BAKER et al., 1951; HARFORD and HEMLING, 1952) that changes in ciliary activity and in mucus secretion were possible factors in the pathogenesis of some diseases of the respiratory tract. Unfortunately, many studies of muco-ciliary function are open to criticism on the following grounds:

(a) the experiments have not been on living animals;

(b) artificial transportation indicators have been used (even small foreign bodies may have a stimulant action on cilia (LUCAS and DOUGLAS, 1935);

(c) assessment of change in ciliary beat frequency has been subjective;

(d) it has been assumed that mucous flow velocity is directly proportional to ciliary beat frequency.

To overcome these criticisms, DALHAMN (1956) has recently studied anaesthetised rats, with their tracheas opened in a specially constructed chamber where temperature and humidity could be controlled. The mucous membrane was inspected directly with a microscope and the rate of flow of mucus was determined by measuring the time required for particles such as shed epithelial cells to travel a given distance. The frequency of ciliary beat was determined by a ciné-photographic recording. The justification for extrapolating these data to the human nasal mucociliary blanket is that there is close resemblance amongst all cilia in the various organs and throughout the Animal Kingdom (FAWCETT, 1954).

DALHAMN found that, when the air in the observation chamber was at 34 °C and 100 per cent relative humidity, the normal mucous flow rate was 13·5 mm/min and the frequency of ciliary beat was about 20/sec. When the relative humidity in the chamber was reduced to 70 per cent, there was no discernible reduction in ciliary activity ofter one hour, but ciliary movement ceased after 8–10 min when the relative humidity was reduced to 50 per cent. Data on the influence of atmospheric pollutants was obtained by protracted exposure to sulphur dioxide in a concentration of 10 p.p.m. This produced retardation of mucous flow, thickening of the mucous blanket and, in some cases, slowing of ciliary activity. We should bear in mind that 5,000,000 tons of sulphur dioxide are passed into the atmosphere in Great Britain each year, although the recorded level of sulphur dioxide has not exceeded 0·15 p.p.m. (D.S.I.R., 1955). It is possible, however, that there may be a cumulative effect.

Using the same technique, DALHAMN has also shown that ciliary movement invariably ceases after 5 min exposure to cigarette smoke (DALHAMN, 1959).

Human physiological experiments

Techniques are now available for measuring human nasal function with little or no intra-nasal instrumentation. Because of the sensitivity of the nose to physical stimuli this is important. Appropriate techniques are listed in Table 3.

Recently, COLE (1953a, b; 1954a) has done a considerable amount of work on moisture and heat relationship in the respiratory tract, when varying climatic conditions ranging from Arctic to tropical have been simulated. He found that, with a normally clothed subject at rest and breathing air over this range of conditions, the inspiratory air in the pharynx was at a temperature of 31–37 °C and little, if anything, below full saturation. Further contributions to the topic under discussion can be made by an extension of COLE's work to include the influence of changing climatic conditions and the measurement of other nasal functions such as patency and mucosal vascular responses. The use of an artificial climatic room would be indicated. It should then be possible to state more precisely optimum environmental air conditions, both static and in respect of rates of change. HEETDERKS (1927) has stated that an environmental temperature of 13–18 °C with a relative humidity

of 50–60 per cent might be regarded as optimal for the nose. Under these conditions every subject showed slight swelling of the turbinates, and nasal secretion was scantily distributed over the nasal mucosa.

TABLE 3. METHODS FOR INVESTIGATING HUMAN NASAL FUNCTIONS

1. Olfaction.
   A. Subjective
      Sniffing olfactometry (JONES, 1955).
   B. Objective
      Utilizing electrodermal response (SEMERIA, 1956).
2. Nasal Air-flow, i.e. converse of nasal patency. Pre-arranged flow. Oscillographic recording of pressure differential using strain-gauge manometer across nose (SEEBOHM and HAMILTON, 1958). Improved by taking into account the non-linearity of pressure-to-flow relationship. (TONNDORF, 1958).
3. Heating of inspired air. Thermistor (resistance element of low thermal inertia) coupled through a resistance bridge network and a D.C. amplifier to an oscilloscope (COLE, 1954a).
4. Humidification of inspired air. Thermo-electric micro-psychrometry (INGELSTEDT, 1956).
5. Vascular reactivity of the mucosa.
   (a) Photo-electric plethysmography (HERTZMAN and DILLON, 1939; DAVIS and HERTZMAN, 1957).
   (b) Mucosal surface temperature. Use of thermo-couple (MUDD et al., 1921; RALSTON and KERR, 1945).
   (c) Submucosal temperature. Thermo-couple mounted within tip of a hypodermic needle (COLE, 1954).

Epidemiological investigations

(a) *With respect to air-conditioning* (*Artificial climate studies*)—Three separate studies indicate that air-conditioning does not predispose to respiratory infections. McCORD (1941) says that the offices of the Detroit Edison Company were in two large buildings side by side with about 875 employees in each, but only one building was air-conditioned. There was no significant difference in the prevalence or attack rate of respiratory infections for the two groups. The New Metropolitan Life Insurance Company in the U.S.A. also had two similar buildings, only one of which was air-conditioned. Each building accommodated over 5000 employees, McCONNELL et al. (1937) reported that the air-conditioning of the one building had no measurable effect on the incidence or duration of absences either for upper respiratory tract infections or for non-respiratory illnesses. BRISTOL (1938) investigated the incidence, character and duration of sickness in a group of 2000 women over a period of three years. All these women worked in one factory, but half were accommodated in air-conditioned rooms, and half were accommodated in rooms that were not air-conditioned but were ventilated by the usual mechanical and natural methods. There was no difference between the two groups.

It might be objected that the modification of environmental air that operated under the conditions of these studies occurred for a period of less than one quarter of the month-by-month life of these subjects. Different results might have been produced if we were able to compare people who were living continuously in an air-conditioned environment with a group who were not. In practice, such conditions are difficult to find. Two exceptions occur. First, there is the case of premature infants, which are now kept in continuously air-conditioned nurseries. BLACKFAN

et al. (1933), found that 26·5 per cent of premature infants in unconditioned nurseries died from acute and chronic infections, but there were no deaths over the same period of time in air-conditioned nurseries with a relative humidity of 50–70 per cent. Secondly, there is the case of the nuclear submarine. Here, a group of people may live for weeks in an independent, contained and finite atmosphere. There is, however, very little sickness apart from the customary respiratory epidemics at the beginning of a cruise before the crew become immune to each others' strains of pathogenic micro-organisms.   The dangers in these microcosms arise not so much from biological as from physical agents. Apart from radiation hazards, there may be chemical hazards. The chief source of carbon monoxide production, previously linked with diesel exhaust fumes, has now been shown to be due to tobacco smoke (EBERSOLE, 1958). These two groups, of course, are not representative of the general population.

An investigation by HOUGHTEN *et al.* (1938) showed that, in practice, so-called "air-conditioning shock" is infrequent. The reactions of 274 office workers to summer cooling and air-conditioning were studied. No especially unfavourable reactions were noticed in connection with movement into or out of air-conditioned rooms.

(b) *Geographical studies* (*Natural climate studies*)—A consideration of the various methods with portable diagnostic criteria that might be applicable to epidemiological studies of nasal dysfunction yields the conclusion that only three are possibly suitable:

(1) Photographic—anterior photo-rhinoscopy;
(2) Radiographic—paranasal sinus projections (SAMUEL, 1952; LYONS and DENNY, 1955);
(3) Cytological—the wiped nasal smear (BRYAN, 1957).

The various nasal function tests listed in Table 3 require relatively complicated equipment, unlike the simpler lower respiratory tract function tests which are now available for epidemiological use (McKERROW *et al.*, 1960; WRIGHT and McKERROW 1959). Even olfactometry requires a room or booth with an air purifier. A mobile unit might be able to accommodate all this equipment, but the big disadvantage is the complicated time patterns that these nasal functions pursue. Consequently, epidemiological studies in nasal dysfunction must inevitably be restricted to that of the prevalence (or attack rate) of nasal diseases. Sinusitis will probably be considered the nasal disease of prime concern, especially when considered in relation to the subject matter under consideration. Acute sinusitis is a frequent complication of upper respiratory tract infection, so we shall primarily concern ourselves with chronic sinusitis. This condition most frequently involves the maxillary sinuses, and the best single diagnostic test of chronic maxillary sinusitis is X-ray photography (WISSLER *et al.*, 1954). There are, however, at least fifteen radiographic projections for sinus views (LYONS and DENNY, 1955). The universally used projection for the maxillary sinuses is the occipito-mental one of WALTERS and WALDRON (1915). An epidemiological study of nasal dysfunction in respect of environmental air would therefore be based on a radiographic survey of the sinuses of the relevant sample populations. Although we have already employed such a survey procedure for other investigations we have not used either of the other two methods which

were suggested as possibly applicable to epidemiological studies. Photo-rhinoscopy is complicated by requiring a comparatively great depth of focus, and it is doubtful whether it would be able to add much to the radiological data. In contrast, the wiped nasal smear (BRYAN, 1957) might prove a useful adjunct to radiography. Staining by the HANSEL (1955) method will show up granulocytes and mononuclear cells and provide an index of the inflammatory components in the sinusitis, whilst staining by the Papanicolau technique will show up specific patterns of structural change within the ciliated columnar epithelial cells. Goblet cell formation, due to intracellular allergic oedema, is an index of the allergic components in the sinusitis.* Goblet cell formation is more constantly present in allergic noses than is either eosinophil production (BRYAN, 1957) or polypus formation.

We have found that there is considerable observer variation in the interpretation of occipito-mental skull X-rays. This is illustrated in Table 4. Consequently, the films must be reported on by at least three people experienced in reading sinus X-rays. The modal opinion is recorded as the correct diagnosis, and from these results a radiographic index of the prevalence of chronic sinusitis may be obtained analogous to the electrocardiographic index of the prevalence of ischaemic heart disease (THOMAS et al., 1958).

The clinico-pathological significance of sinus opacities either localized or generalized is not as obvious as it might seem at first sight. Excluding osteomas and foreign bodies, these opacities are invariably the result of inflammatory sinus disease. The questions to be answered are:

(1) Is the inflammatory disease process acute or chronic?
(2) If acute, it is an acute episode in an otherwise normal sinus or is it an acute exacerbation of a chronic process?
(3) If chronic, is the process active or inactive?
(4) Is there an allergic factor?

Questions (1) and (2) will be answered by enquiring whether the subject has a "cold" and by X-raying three months later. The prevalence may then be found to be halved (BJUGGREN et al., 1952), or quartered (NITSCH, 1957) if the sample comprises children. In clinical practice, question (3) would be answered by antral puncture and aspiration and/or irrigation of the sinus. For obvious reasons this procedure cannot be employed in epidemiological studies. In such studies reliance must be placed on questionnaires. BUCH's (1949) data indicated that about 65 per cent of cases with radiological signs in respect of the sinuses are cases of active chronic sinusitis and 10 per cent are false positives. The remaining 25 per cent show inflammatory change as evidenced by biopsy of the antral mucosa (PETRI, 1949). The demonstration of active inflammatory sinusitis does not preclude an allergic factor in the pathogenosis. DISHOECK and FRANSSEN (1957) state that an allergic factor is demonstrable in more than 60 per cent of cases of chronic purulent sinusitis. A tissue hypersensitivity is said to be a common cause of radiographic signs in the paranasal sinuses of younger children, responding to a single injection of hydrocortisone into the antrum (MASPÉTIOL et al., 1955).

The various factors to be considered in an epidemiological survey of sinusitis are listed in Table 5. We have included air-pollutants in this table because of the

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*Pathological changes in the mucosa of the nasal cavities reflect changes in the mucosa of the sinuses.

TABLE 4. MAXILLARY SINUSES

Obs 'A' (Individual diagnosis)	Preponderant Diagnosis						
	Normal	Generalized opacity	Fluid level	Mucosal thickening	Cyst or polyp	F.B.	Total
Normal	414	0	2	5	1	2	424
Generalized opacity	8	19	0	5	0	0	32
Fluid level	1	0	2	1	0	0	4
Mucosal thickening	61	1	0	40	4	0	106
Cyst or polyp	0	0	0	0	4	0	4
F.B.	0	0	0	0	0	0	0
Total	484	20	4	51	9	2	570

The table demonstrates inter-observer variation in the reading of X-rays of the maxillary sinuses. This particular reader (Observer 'A') was an otologist of 10 years' experience. The "preponderant diagnosis" is the modal opinion of four doctors (including Observer 'A') who reported on 285 sinus X-rays of a random sample of a rural population. The diagonal line indicates where there is agreement between Observer 'A' and the modal opinion. Note the gross over-reading with respect to the "mucosal thickening".

correlation of the prevalence of bronchitis and atmospheric deposit (STOCKS, 1959) and the non-genetic association of bronchitis and sinusitis (HOFFMAN and WORTH, 1958; MALFATTI, 1957; PRICE, 1951). It would be surprising if the various atmospheric pollutants that can damage the lower respiratory tract do not prove toxic for the mucosa of the paranasal sinuses also. We have recently shown that, for adults, the prevalence of the nasal carriage of bacteria is dependent upon age and sex. "Nasal airway" is listed in Table 5 because of the importance which contemporary nasal physiology (PROETZ, 1941) attaches to this in the pathogenesis of sinusitis. No test of nasal patency which meets epidemiological criteria is yet available.

B

TABLE 5a. EXOGENOUS FACTORS TO BE CONSIDERED IN EPIDEMIOLOGICAL STUDY OF
SINUSITIS

A. Climatic   Humidity; Temperature.
   Measurements: *WBT, DBT*, Air Velocity, Black Globe thermometer
                         temperature.
                         "Envirec" (HOSEY and MENDENHALL, 1959).

B. Air contaminants
   1. Gaseous: (a) Gases, e.g. SO_2.
                         (b) Vapours, e.g. hydrocarbons

   2. Particulate: (a) Dust: deposited matter $>50\mu$
                         (b) Smoke: suspended matter $<50\mu$

   3. Biological: i.e. atmospheric flora. Bacteria; viruses; pollens; spores
                         and moulds.

C. Occupational   Probably in terms of 'A' and 'B'.

D. Nutritional
   Measurement: Oral questionnaire may be more valid than sample
                         weighing methods (PASRICHA, 1959).

TABLE 5b. ENDOGENOUS FACTORS TO BE CONSIDERED IN EPIDEMIOLOGICAL STUDY
OF SINUSITIS

A. Allergy
   Underlying allergic factor in 70 per cent chronic sinus infections (SHAMBAUGH,
   1945).
   Measurement: 1. Wiped nasal smear (BRYAN, 1957). More than 70 per cent
                      children with sinusitis show eosinophils in nasal smear
                      (GORDON, 1955).
                   2. Blood: Eosinophilia.

B. Associated diseases
   Respiratory disease—$2\frac{1}{2}$ times greater prevalence of sinus disease.
   Ear disease   —$1\frac{1}{2}$ times greater prevalence of sinus disease (BUCH, 1949).
   Measurement: "Bronchitis" questionnaire (FAIRBAIRN *et al.*, 1959).
                Otoscopy; chest X-ray.

C. Genetic syndromes
   KARTAGENER (1933); MOUNIER-KUHN (1944)
   "Lung-nose" syndrome inherited as dominant (TORGERSEN, 1952).
   Measurement: Blood group; prevalence of frontal sinus agenesis (?).

D. Nasal airway
   But no valid reliable method for determining patency in a single measurement.

E. Nasal carriage of bacteria
   Nasal carrier rate for pneumococci correlated with radiological changes in
   children (TUNEVALL, 1952).
   Measurement: Streptomycin sulphate crystal violet blood-agar culture medium.

F. Sinus disease in early life
   Might predispose to chronic or subsequent sinus disease, in analogy to pneumati-
   zation of mastoids.
   Measurement: Antro-nasal index (PESTI, 1953).

G. Ethnological
   Platyrrhine type of nose in inhabitants of hot moist climates, e.g. Negro; leptor-
   rhine, e.g. Eskimo, in cold, dry climates (THOMSON and BUXTON, 1923).
   Nasal index correlates with absolute humidity (WEINER, 1954).
   Implies climatic adaptation and ? less prone to climatic-dependant nasal disease.

It might be thought that recording the presence or absence of a deviated nasal
septum should be considered. However, although a deviated septum is rare in
Central African Negroes (MANSON–BAHR, 1956) in one European sample which
was examined (MOE, 1942) there was only one undeviated septum. This septum
had been subject to surgical correction.

CONCLUSIONS

The precise importance of environmental air conditions in the pathogenesis of nasal dysfunction and their influence on the prevalence of nasal disease has yet to be elucidated. Available evidence, however, indicates that artificial climates, in the sense of air-conditioning of offices or factories, do not influence the prevalence or attack rate of upper respiratory or other diseases.

It would seem that further enquiries into the relationship between nasal dysfunction and environmental air conditions must primarily take the form of epidemiological investigations. Feasibility studies that we have conducted indicate that such investigations are possible using radiographic methods.

For purposes of surveys, concurrent radiological examination of the chest and of the sinuses has been advocated (LEIBER and PABST, 1953; MEUSCHKE, 1956). It should therefore be possible to combine a "sinusitis" survey of the type envisaged with a "bronchitis" survey of the type conducted by HIGGINS (1957); HIGGINS and COCHRAN (1958) and HIGGINS et al.(1956). To allow this "respiratory tract" concept instead of the "E.N.T." concept to influence the approach to these investigations might prove more rewarding.

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STUDIES ON THE CHEMICAL PROPERTIES OF CHRYSOTILE IN RELATION TO ASBESTOSIS

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Abstract—The dissolution of chrysotile asbestos in aqueous media has been studied. Although chrysotile yields very little monosilicic acid in water at 25 °C, much more monosilicic acid appears if the extract is heated to 90 °C. The observations are consistent with removal of magnesium and the release of minute, two-dimensional "flakes" of the silica lattice. It is conceivable that these silica flakes, which would have a large surface area, could pack into the cytoplasm of monocytes after the break-up of an asbestosis body. A reaction similar to that normally evoked by fine silica particles would then follow. The chrysotile fibre disintegrates more readily with alternating acid and alkaline conditions than under the influence of either acid or alkali alone.

Two rival theories of the aetiology of asbestosis have been reviewed (HOLT, 1957). One theory assumes that the disease is due to mechanical irritation set up by asbestos fibres, the other that it is an indirect silicosis due to the liberation of silicic acid by the decomposition of asbestos in the lung. Direct proof of either theory has not been possible. The results of animal experiments have been used to support the mechanical theory, but it has been recognized that only the early stages of asbestosis have been reproduced in small laboratory animals, although typical asbestosis was found in a dog that had been living for some years in an asbestos works (SCHUSTER, 1931). The recent work of BEATTIE (1960) suggests that the asbestos fibre is inactivated in the lung by a protein allied to collagen, which coats the fibre forming the asbestosis body. It is not until this coating is damaged or removed that the asbestos or its degradation product produces fibrosis. This new aspect of the problem must stimulate research on the formation and disintegration of the asbestosis body and on the nature of the degradation, if any, of the asbestos fibre. A more exhaustive study of the chemical properties of asbestos itself is needed.

Some studies have already been made on the effects of water, acids and alkalis on asbestos but the results are confused. For example, KING and McGEORGE (1938) reported the solubility, as measured by the concentration of silica, to be very low in ascitic fluid, less than that of quartz. BRISCOE *et al.* (1937), measuring the rate of dissolution at 100°, found a much higher value than for quartz, e.g., asbestos gave 25 mg SiO_2/100 ml. These anomalies have never been explained.

This report describes studies on the rate of dissolution of chrysotile at several temperatures in neutral, acid and alkaline media, and the analyses of the extracts.

Material—Opened South African chrysotile fibre was used. Material of unknown composition, which may have a chemical structure resembling that of fibrous asbestos, but is in the form of plates, always accompanies fibrous asbestos and cannot be completely separated from it. The fibres were separated as far as possible from this other mineral but some platy material was certainly present.

EXPERIMENTAL

Rates of dissolution (*methods*)—Samples of asbestos (2g) were allowed to stand in water (400 ml), hydrochloric acid (0·1N) or sodium hydroxide (0·1N) for various time intervals, at 25°, 37° and 90°. Polythene bottles were used at the lower temperatures, but were impracticable at 90°, and Hysil glass flasks were then used. Each sample was filtered through a Whatman no. 40 paper after the required time, cooled to room temperature, and the amount of silica and magnesium in an aliquot of the filtrate was determined. The yellow silico-molybdate method (KING *et al.*, 1955) was used to estimate the silica colorimetrically. This method evaluates only orthosilicic and disilicic acids; higher polymers give no colour with the molybdate reagent. A volumetric method, using ethylenediamine tetracetic acid (CHENG *et al.*, 1952) was used to estimate magnesium.

RESULTS

Dissolution in water at 25 °C—Little magnesium or molybdate-reactive (M.R.) silica appear in solution even after several weeks (Table 1). The small and somewhat variable figures cannot give an accurate value, but the ratio MgO/SiO_2 is about 10:1.

TABLE 1. DISSOLUTION OF CHRYSOTILE IN WATER AT 25°

Extraction time (days)	Mg (mg/100 ml)	SiO_2 (mg/100 ml)
1	0·4	<0·2
2	0·5	<0·2
3	0·5	0·0
4	0·6	0·0
5	0·7	<0·2
6	0·7	0·0
7	0·9	<0·2
21	0·8	0·0
28	1·4	<0·2
42	1·0	<0·2
56	2·2	<0·2
70	1·7	<0·2

When a similar clear, filtered extract is heated at 90° for 3–6 hr the concentration of magnesium in solution is unchanged; the amount of dissolved M.R. silica slowly increases (Table 2). The very small initial concentration of silica makes

TABLE 2

Duration of extraction (days)	Mg(mg/100 ml)			SiO_2(mg/100 ml)		
	initial	after 3 hr at 90°	after 6 hr at 90°	initial	after 3 hr at 90°	after 6 hr at 90°
5	1·05	1·25	1·05	0·12	0·72	1·36
21	2·0	2·05	2·05	0·04	1·16	2·4
23	2·15	2·10	2·10	0·08	0·84	1·4

Extracted at 35°, 1 g asbestos: 200 ml water

accurate measurement impossible, but the increase cannot be less than tenfold. The increase implies that siliceous particles of some kind, which have passed through the filter but are too small to be visible, are being broken down to simple orthosilicic acid. The possible nature of these particles will be discussed later.

Dissolution in water at 90 °C. (Table 3)—An appreciable amount of silica appears in solution, the amount steadily increasing during 6 hr. The concentration of magnesium is constant after 15–30 min. Alteration in the chrysotile/water ratio resulted in the amount of dissolved silica increasing with the mass of chrysotile extracted up to the ratio of 0·5 g chrysotile/100 g water (Table 4).

TABLE 3

Extraction time (hr)	Mg (mg/100ml)	SiO$_2$ (mg/100 ml)
¼	0·4	0·2
½	0·5	0·4
1	0·5	0·5
2	0·5	0·7
3	0·5	1·2
4	0·5	1·3
5	0·6	1·6
6	0·5	2·2

0·5 g asbestos extracted with 100 ml water at 90 °C

TABLE 4

Wt. extracted/ 100ml water(g)	Mg (mg/100 ml)	SiO$_2$ (mg/100 ml)
0·13	0·10	0·16
0·25	0·25	0·28
0·5	0·25	0·36
1·0	0·65	0·36

Extracted with water for 0·5 hr at 85–90°

Repeated extractions of a sample showed that the amount of silica and magnesium decreased in subsequent extractions. After four or five extractions there was practically no silica or magnesium in the extract (Table 5).

TABLE 5. REPEATED EXTRACTION OF CHRYSOTILE WITH WATER AT 85–90°

No. of extractions	Mg (mg/100 ml)	SiO$_2$ (mg/100ml)
1	0·4	0·2
2	0·1	<0·1
3	0·0	<0·1
4	0·1	0·0
5	0·1	0·0
6	0·1	0·0

Duration of extraction: 15 min. Asbestos: water = 0·5 g/100 ml

Dissolution in 0·1*N* HCl *at* 37 °C (Table 6)—Much more silica and magnesium appear in solution. Throughout the course of extraction the increase in the concentration of the one component is parallel with that of the other (Fig. 1). The

TABLE 6. DISSOLUTION OF CHRYSOTILE IN 0·1N HCl AT 37°

Extraction time (days)	Mg (mg/100 ml)	SiO$_2$ (mg/100 ml)
7	56·4	14·3
14	69·3	17·3
21	79·5	21·0
28	84·6	21·2
35	87 2	22·0
45	97·9	18·8
49	97·4	20·6
66	100	20
77	108	25
91	109	22
132	100	20

silica concentration increases rapidly to about 20 mg/100 ml (probably a saturated solution) and the magnesium concentration to about 110 mg/100 ml in about 7 weeks. The pH increases from 1·5 to 2·4 in 19 weeks.
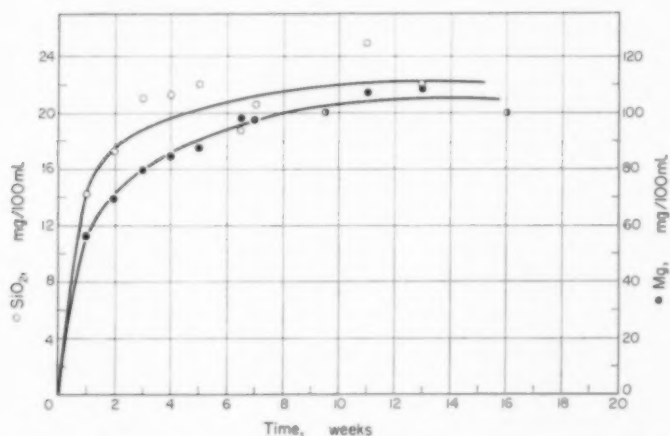
FIG. 1. Dissolution of chrysotile in 0·1N hydrochloric acid at 37 °C. Both magnesium and silica pass into solution, the concentration of both becoming nearly constant when the silica concentration has risen to about 20 mg/100 ml.

Dissolution in 0·1*N* HCl *at* 90 °C—The concentrations of both the magnesium and silica rapidly increase, and the final and maximum concentration of M.R. silicic acid after 3 hr is identical with that reached on extraction with acid at 37 °C after 7 weeks (Table 7). There is little change in pH. The concentration of magnesium is lower than that reached at 37 °C, perhaps because of the hydrolysis of magnesium chloride at the higher temperature, the shift in equilibrium favouring the sparingly soluble magnesium hydroxide.

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Table 7. Dissolution of chrysotile in 0·1N HCl at 90°

Extraction time (min)	Mg (mg/100 ml)	SiO₂ (mg/100 ml)
10	16·9	2·2
15	23·1	3·0
15	23·1	3·8
30	36·9	7·1
45	36·9	7·3
45	46·2	8·2
60	35·4	8·0
60	35·4	8·0
75	44·6	11·0
90	46·7	11·5
105	64·1	18·0
120	72·3	19·0
150	66·7	20·0
180	61·5	20·0

Dissolution in 0·1N NaOH *at* 37 °C—Negligible amounts of magnesium or silica appear in the extracts (Table 8); the small concentration of silicic acid appearing in the first two or three weeks seems to be actually reduced later.

Dissolution of acid-treated chrysotile in 0·1N NaOH *at* 37 °C—The silica concentration of the extract increased rapidly, a value of 20 mg SiO₂/100 ml (near saturation) being attained in one week (Table 8 and Fig. 2). No magnesium was detected. Before filtration the extract appeared cloudy, possibly due to precipitated magnesium hydroxide.
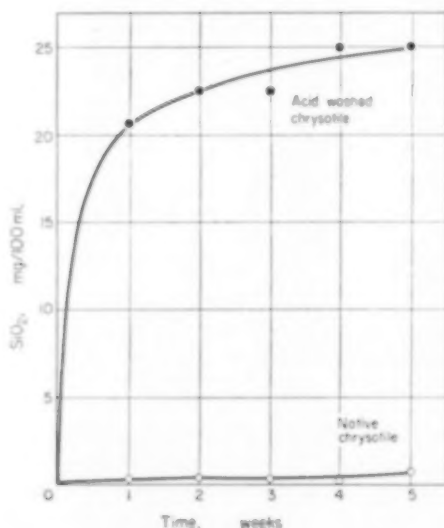
Fig. 2. Dissolution of chrysotile and acid-washed chrysotile in 0·1N sodium hydroxide at 37 °C. The rapid dissolution of the acid-washed material indicates that the magnesium normally acts as a protective layer.

TABLE 8. DISSOLUTION OF CHRYSOTILE IN 0·1N NaOH AT 37°

Extraction time	Untreated chrysotile		Acid-washed chrysotile	
(days)	Mg (mg/100 ml)	SiO_2 (mg/100 ml)	Mg (mg/100 ml)	SiO_2 (mg/100 ml)
7	0·1	0·3	0	20·7
14	0·1	0·4	0	22·5
21	0·1	0·3	0	22·5
28	0	0·2	0	25·0
3 ǐ	0	0·7	0	25·0
42	0	0		
49	0	0·1		

DISCUSSION

These results generally confirm KING's observation that the amount of molybdate-reactive silica released when chrysotile is extracted with water at 25 °C is small. The extract contains more magnesium; after some days the ratio of magnesium to molybdate-reactive silica is certainly greater than 10:1. The empirical formula of chrysotile is $Mg_3Si_2O_5(OH)_4$ and the anomaly that much more magnesium than silica is found in solution needs explanation. LEITMEIER (1914) equilibrated serpentine, a non-fibrous magnesium silicate, with water. After 6 months 100 ml of the extract contained 3 g magnesia and 0·2 g silica, thus giving a similar ratio.

When extracts of chrysotile were heated at 90° for several hours, then cooled to room temperature, the amount of molybdate-reactive silica increased from 0·2 mg/100 ml to 1·4–2·8 mg/100 ml. There are three possible explanations of this phenomenon.

(a) An insoluble colloidal precipitate of a magnesium silicate forms, or very fine particles of some other mineral are present which are not retained by a filter. It must be assumed that the silicate is not molybdate-reactive, but that it is decomposed on prolonged heating with water. This is improbable because a magnesium silicate would be likely to react with the sulphuric acid added with the molybdate reagent, and it is disproved because there is no increase in the magnesium content of the extract on heating. Moreover, the solutions were clear and did not show the turbidity usually associated with such a colloidal solution.

(b) Part of the silicic acid may have been present as polysilicic acid which is not molybdate reactive. However, the fact that the concentration of the silicic acid was very much below that of a saturated solution of orthosilicic acid means that if polysilicic acid were present it would depolymerize to a considerable extent in the time allowed for extraction.

(c) Chrysotile is layered with parallel siloxan (Si-O) sheets and is probably similar to kaolin, but it has Mg_3 in place of Al_2 between the siloxan layers. The sheets are rolled up in the chrysotile fibre, the central hole being filled with amorphous material. The water may remove the magnesium ions as magnesium hydroxide, leaving the two-dimensional sheets of –SiO– ions which would be invisible and much too small for retention by a filter. They may not be immediately broken down by water at 25 °C but are more readily hydrolysed at 90 °C. The breakdown of these structures would produce orthosilicic acid but would not involve either change in pH or the production of magnesium ions.

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The direct extraction of chrysotile at 90 °C would result in the immediate release of the bulk of the silicic acid as ortho-silicic acid. These effects were, in fact, observed. At 90 °C, the low magnesium content of the extract is explained by the low solubility of magnesium hydroxide, the solubility of which decreases with increasing temperature. (Solubility in water at 18 °C is about 0·0002 and at 100 °C about 0·00007 g mol per litre.) This explanation of the dissolution of chrysotile in water at 90 °C and its insolubility at 25 °C explains and confirms the apparently contradictory results of KING and MCGEORGE (1938) and BRISCOE et al. (1937), mentioned earlier.

This hypothesis and the assumption that the outer layer of a normal asbestos fibre consists of hydrated magnesium ions may be applied to the other solubility data. Because of the very low solubility of magnesium hydroxide, the dissolution of the outer layer of hydrated magnesium would be retarded by hydroxyl ions (alkali) and the outer layer prevents the dissolution of the adjacent layer of silica ions. Acid, on the other hand, will remove the outer layer of magnesium ions, allowing the dissolution of the silica layer; thus at 37 °C alkaline extracts contained negligible amounts of either magnesium or silica, acid extracts contained 120 mg $Mg/100$ ml and 20 mg $SiO_2/100$ ml. It is relevant that, in contrast, quartz is more soluble in alkaline than in acid solutions. However, an acid-extracted sample of chrysotile gave 25 mg $SiO_2/100$ ml when treated with sodium hydroxide. Evidently acid treatment leaves a silica layer on the surface of the asbestos fibres and this is rapidly dissolved by a sodium hydroxide solution. No magnesium is found in solution. Presumably, once the silica is stripped from the surface an insoluble magnesium hydroxide layer is again formed and dissolution is inhibited unless a further acid treatment is given. Dissolution of the chrysotile proceeds in acid solution, then, but the asbestos is even more susceptible to alternating acid and alkaline conditions.

In acid, chrysotile dissolved to give a maximum silica concentration of rather more than 20 mg $SiO_2/100$ ml. This represents a saturated solution of orthosilicic acid at normal temperatures and it is not clear, without further experiments, whether the limit to the amount of dissolved silica is due to the extract becoming saturated or primarily to the arrest of the process of dissolution.

In vitro experiments of this type cannot prove or disprove either theory of the aetiology of asbestosis, they can only suggest that a theory is, or is not, feasible. The new data on the breakdown of asbestos suggests that, in the lung at pH 7, dissolution will be slow, a coating of sparingly soluble magnesium hydroxide inhibiting further action. The magnesium hydroxide may well serve also to adsorb the protein in the initial phase of the production of the asbestosis body.

The more rapid dissolution which results from alternating acid and alkaline conditions may be relevant to the rapid development of asbestosis in persons who have had asbestos fibres and asbestosis bodies lying inert in the lungs for years. MENKIN (1951) reported that, in an inflammatory reaction, the tissues become first alkaline and then acid. This process might accelerate dissolution of asbestos fibres and the release of silica, which process would also accelerate the production of asbestotic lesions if asbestosis is a chemical process.

This is in no way contrary to BEATTIE's theory that the break-up of the capsule of the asbestosis body is a prerequisite to the production of fibrosis. The capsule would presumably protect the silica framework of the asbestos fibre from solvent

action although it would not necessarily prevent the diffusion of magnesium ions away from the fibre. If this occurred at all, a decrease in pH would accelerate the process, and the possibility that the breakdown of the capsule may be related to the removal of magnesium must be borne in mind.

Rapid asbestosis would then be expected to accompany pathological conditions such as pneumonia and bronchitis. Both the alkaline and the acid inflammatory reactions result in increased local capillary permeability, and this, in itself, would assist in the removal of the magnesium hydroxide layers from the fibres.

If silica is released from chrysotile fibres in a form other than orthosilicic acid, it must be in the form of silica sheets, which resemble an orthosilicic acid molecule in one dimension, but are of considerable size and similar to silica in the other dimensions. Thicker formations could occur if the sheets were stacked and held together by hydrogen bonds between hydroxyl groups. Presumably these particles would be ingested by phagocytes in the lung as are particles of silica dust. Because they are thin, they would be invisible but could pack tightly in the cytoplasm; presumably a reaction would then occur as in pure silicosis.

All observations on the properties of asbestos are subject to the reservation that results may be affected by non-fibrous material by which it is contaminated. There is no method by which the two types of material may be separated. With this qualification these studies indicate that a chemical theory of asbestosis is at least feasible. If the breakdown of chrysotile follows the same course *in vivo* as it does *in vitro*, a pneumoconiosis having a general resemblance to silicosis would be expected.

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A METHOD FOR THE ESTIMATION OF PARTICULATE ATMOSPHERIC CONTAMINANTS IN TRACE AMOUNTS

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Abstract—A technique is described for taking very large air samples and filtering out particulate contaminants. A wool resin filter media is used, enabling high flow rates up to 0·5 m³/min to be achieved with a pressure drop low enough to permit the use of a centrifugal blower. The extension to portable apparatus is also described.

IN a recent environmental investigation in connection with a health survey in the pottery industry it was necessary to estimate an airborne contaminant which was thought to be hydrofluoric acid. For the first determination sintered plate gas scrubbers were used, containing a suitable solution, and in order to check efficiency two were connected in series and duplicate runs were made. It was known from previous work that scrubbers of the type used were almost 100 per cent efficient against acid gases, but in spite of the use of various absorbants it was found that the percentage of contaminant trapped in the second scrubber in the train was of the order of 50 per cent of the amount trapped in the first. In addition repeatable results could not be obtained.

As it was necessary to achieve in the estimation a sensitivity of better than 1 p.p.m. it was thought that contamination of the sample during manipulation might have occurred, and accordingly aseptic conditions were observed throughout the work but no improvement in the figures was obtained.

From these results and from observations of the Tyndall effect on a beam of light it was concluded that the contaminant in the air was not a gas but a particulate solid. A close examination of the location showed that it was likely that the particulate matter existed in a finely divided form, and these and theoretical considerations indicated that the contaminant was likely to be a complex fluoride. This was later indirectly confirmed by X-ray analysis. Samples taken with a thermal precipitator showed that over 80 per cent of the particles were less than $0·4 \mu$, with a substantial proportion less than $0·1 \mu$. In no way other than by sublimation or formation from the gaseous state could particles of this size range have been formed in the process being investigated.

The problem therefore at this stage was to trap efficiently very fine particles while retaining a sufficient airflow to make possible the collection of a large sample so necessary for the accurate determination of the small amount of contaminant present. The use of electrostatic precipitation immediately comes to mind, but of course entails a relatively bulky apparatus which would have limited the scope of the investigation. In order to obtain the desirable characteristics of the device and yet retain portability, a special type of material developed for dust respirators

was used as the filter media.* This material consisted essentially of wool impregnated with electrostatically charged resin particles which will retain their charge for many years. The filter combines the properties of mechanical filtration for coarse particles with the characteristics of electrostatic precipitation for very fine particles. It has been found in fact that such filters have an efficiency of over 99 per cent at $0.4\ \mu$ with increasing efficiency both at larger and smaller particle sizes. This latter factor is of course especially desirable for air sampling apparatus. In spite of this very high filtering efficiency a flow-rate of about 100 l/min can be obtained using a filter 6 cm in diameter with a resistance of 1 in. water gauge. This low resistance cannot of course be obtained with simple conventional filters of a similar size.

Determinations in the field using such filters in the sampling line before the scrubbers showed that over 99 per cent of the contaminant was retained by them. As only trace amounts of fluoride (less than 1 per cent) were found in the scrubbers, subsequent sampling runs were made without their use, enabling the flow rate to be increased from 2 to 250 l/min. These high rates enabled very large air samples to be taken as compared with conventional methods, making the subsequent analytical work less difficult and enabling a truer average sample of the atmosphere to be taken. This latter fact was demonstrated by the remarkable repeatability of the duplicate runs.

With overall resistances of the order of 1 in. water gauge it becomes possible to use small centrifugal blowers which are of course far more efficient in moving large quantities of air for a given power consumption. In addition such blowers are more compact and of far less weight than air pumps. In this particular apparatus a proprietary blower was chosen having a capacity of 500 l/min at 3 in. water gauge. It weighed less than 5 lb and it was thus possible to construct a small portable apparatus, the filters being fitted directly on to the intake of the blower, as illustrated in the photographs (Figs. 1 and 2).

In the initial work a large rotameter (100/500 l/min) was fitted to the pump outlet. This, while suitable for more accurate determinations, may be dispensed with for normal sampling work by measuring the pressure drop across the filter and calculating the volume of air passed from the makers' charts of pump performance. If such readings are taken before and after sampling, a check can be made of filter clogging and the average reading taken for the purpose of calculating the volume. Experience shows that normally the flow rate is reasonably constant.

In view of the small power requirements of the blowers used, the possibility of constructing a portable apparatus operating from storage batteries was investigated. Small cooling blowers originally designed for radar equipment and operating from a 24 V supply were first used. These blowers had a power consumption of some 20 W and could consequently be operated from accumulators for long periods. They weighed less than 2 lb each and gave an air flow of some 100 l/min when used in this particular apparatus. Alternatively it might be possible to use an automobile heater blower, although the apparatus will then be rather larger than the type described above.

Other features revealed during this work were the rapidity and ease of insertion and removal of the filters which are self sealing at the edges, the complete retention of the particular matter in the filter pad during handling, and their relatively low cost.

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* V. Hansen's Resin Filter (DAVIES, 1949).

Up to the present, soluble fluoride dusts, beryllium, iron, arsenic and manganese oxides have been successfully trapped and estimated. The filters could also be used to estimate other particular contaminants, providing (1) a sample of sufficient size is taken to mask any trace impurities which may be present in the filter material and which will appear in the blank determination, and (2) the contaminant can be removed from the filter by a suitable method, e.g. water or acid extraction, wet ashing, etc.

The possibility of using such filters to estimate silica dust is being investigated; it is hoped that information on this and on the possibility of using a method which will reject particles of irrespirable size will be available in the near future.

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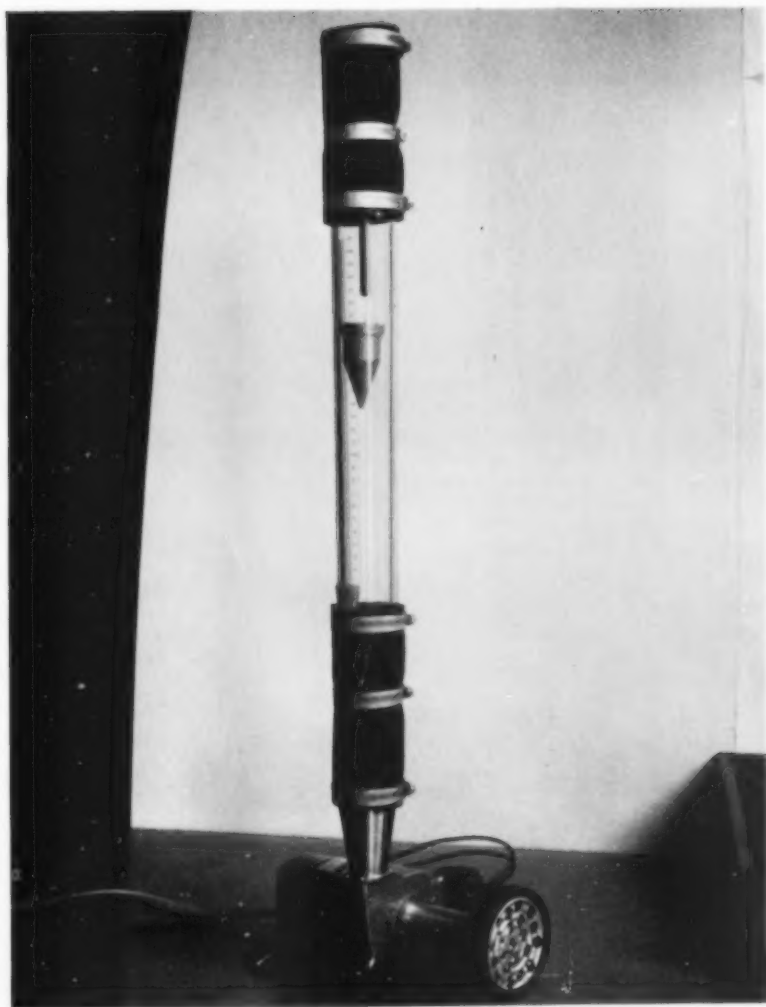
Fig. 1
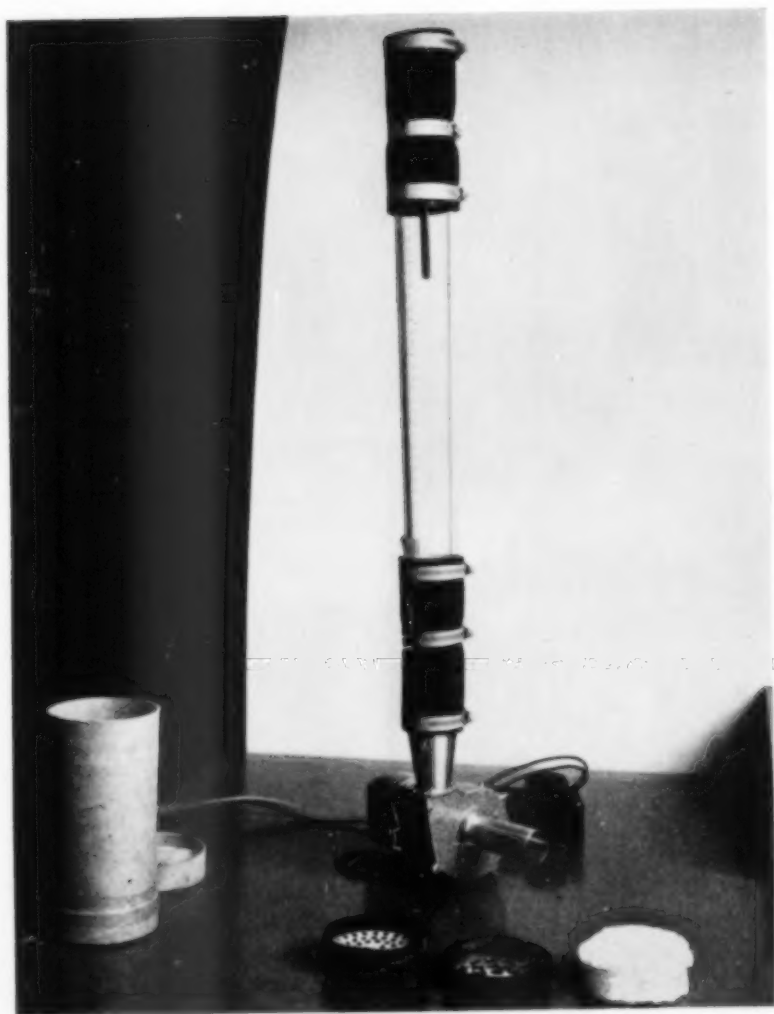
Fig. 2

THE SIZE DISTRIBUTION OF COAL AND ROCK DUSTS IN THE ELECTRON AND OPTICAL MICROSCOPE RANGES

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Abstract—The basic size distribution of airborne coal and rock dusts has been estimated by studying the pattern of comminution of the parent materials. This has been carried out by both optical and electron microscope studies of dust down to $0.05\,\mu$ produced under laboratory conditions.

The relation between the basic size distribution of coal and of rock dusts and the observed distribution of total airborne particulate matter in coal mines has been studied in terms of the degree of initial dust dispersion, of changes due to aggregation and settling, and of the pollution level of the ventilation air. The observed size distribution of airborne mine dust cannot be completely described by a simple mathematical function, but over a restricted size range the function $dN/dD = KD^{-\gamma}$ will describe the distribution when the dust is in the fully dispersed condition. Over a wider size range the quantity of fine dust has never been greater than that which would be predicted by a power law based on the frequencies of larger sizes. In consequence it seems that on the basis of these experiments an extrapolation of the power law to sizes smaller than the resolving limit of the counting system would provide an estimate of the maximum number of fine coal or rock particles.

1. INTRODUCTION

OVER the last fifty years the volume of literature on the size distribution of fragmented minerals has rapidly increased. The industrial literature on the subject is mainly concerned with ground materials from 1 cm down to about 0.01 mm (10 μ), while the literature dealing with the health hazard is mainly concerned with dusts with particles below 10 μ, since particles larger than this do not readily penetrate into the lung. Although it is not known whether there is a lower size limit at which particles cease to be harmful, there has been little information published on the distribution of particle sizes below about 0.5 μ, mainly because these small particles are below the resolving power of optical microscopes which are normally used to study them.

A number of attempts have been made to derive a mathematical function that would describe the size distribution of particles smaller than 10 μ. MARTIN (1923) put forward a simple distribution function of the form $dN/dD = A \exp(-bD)$. This function was used by WYNN and DAWES (1951) to describe the distribution of coal mine dusts over the range 1–6 μ. Examples of more comprehensive theoretical treatments are those of LIENAU (1936), GRIFFITHS (1943) and EVANS (1958). These authors arrived, by different methods, at rather similar conclusions and derived distribution functions of the general form $KD^\gamma \exp(-bD)$. This is similar to the ROSIN and RAMMLER (1933) equation which gives the weight function

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$dW/dD = NbD^{N-1} \exp(-bD^N)$ which the authors state was deduced from probability considerations. This equation is better known in its integrated form which gives weight per cent oversize as $100 \exp(-bD^N)$. BENNETT (1936) developed a more complete theoretical derivation of this weight distribution function. HEYWOOD (1933) applied a similar relation to number as distinct from weight distributions and discussed the implication of this form as D tended to zero.

The theoretical treatments, in general, support the view that the overall distribution would be a product of a power term and an exponential term. At a sufficiently small particle size, however, the exponent bD would be small enough for the exponential term to be sensibly unity and the distribution would thus be described by a simple power law $dN/dD = KD^{-\gamma}$.

This power law relation was shown by GAUDIN (1944) and more recently by HAMILTON and KNIGHT (1958) to extend to sizes of well over $50\,\mu$ with fragmented coal and rock, and GRIMSHAW (1958) showed that it applied to sandstone and limestone fragments from $2\,\mu$ to 10 cm when the parent materials were shattered by explosives.

HODKINSON (1958) summarized experimental results of a number of workers and showed that the $D^{-\gamma}$ function gave a useful mathematical description of each of their size distribution measurements of coal and rock dusts. These distribution measurements included electron microscope evaluations from 0·01 to $3\,\mu$ and sieve and liquid sedimentation analyses from 2 to $100,000\,\mu$. Table 1 and Fig. 1 are reproduced from HODKINSON's summary. The mean of the seven values of γ for coal in Table 1 is 2·5, and for the eleven values of γ for rock it is 2·6. The
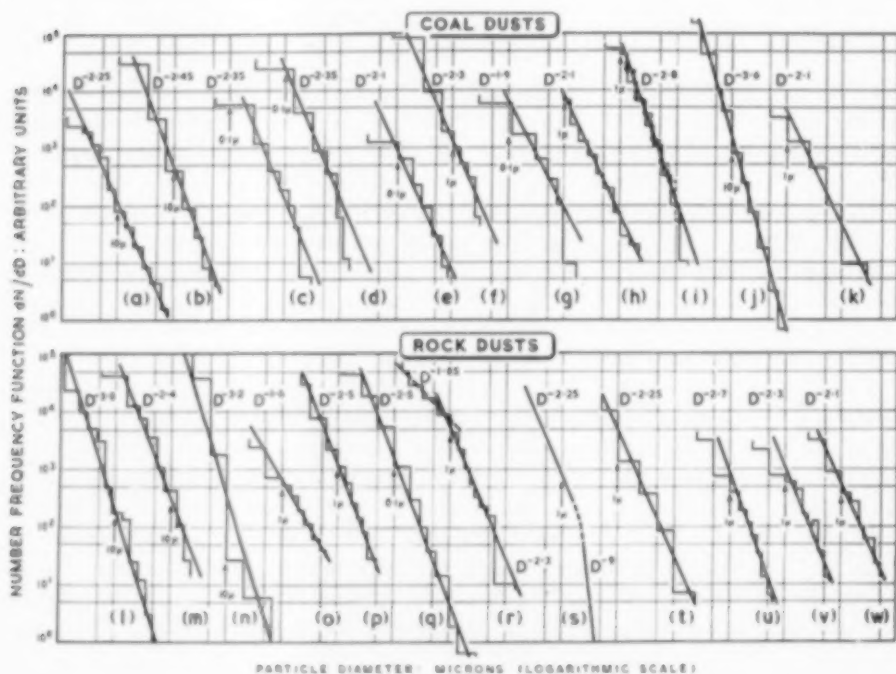
FIG. 1. Size distributions of various microscopic coal and rock dusts.

Table 1. Particle-size analyses of various microscopic coal and rock dusts

Fig.	Workers	Material	Size-analysis technique	Probable range of reliable observation, (μ)	Range fitted by $D^{-\gamma}$ size-distribution law, (μ)	Mean value of γ
		Coal dusts				
(a)	Hamilton and Knight (1958)	Four coals (10–35% volatile) crushed, shattered and drilled	Light microscope	2–75	2–75	2·25 (2·2–2·3)
(b)	Perrot and Kinney (1925)	Crushed anthracite culm	Light microscope	1–50	1–35	2·45
(c)–(g)	McCartney (1945)	Five different coals, crushed	Electron microscope	0·05–2	0·1–1·5	2·2 (1·9–2·35)
(h)	Stanley (private communication)	Ground bituminous coal	Light microscope	1–20	1–25	2·1
(i)	Dawes, Burdekin and Slack (1957)	Airborne dust from ground bituminous coal	Thermal precipitator and light microscope	1–12·5	1–10	2·8
(j)	Dawes, Burdekin and Slack (1957)	Ground bituminous coal	Liquid sedimentation	2–100	2–100	3·6
(k)	Burdekin and Dawes (1958)	Airborne coal dusts in mines	Thermal precipitator and light microscope	1–25	1·5–25	2·1 (1·0–3·5)
		Rock dusts				
(l)	Hamilton and Knight (1958)	Three sandstones, crushed and drilled	Light microscope	2–75	2–75	2·9 (2·7–3·1)
(m)	Brown (1951)	Quartz monzonite, drilled	Light microscope	1–20	1·5–15	2·4
—	Brown (1951)	Coarse fraction of above	Sieve	50–2000	50–2000	3·2
(n)	Grimshaw (1958)	Limestone, blasted	Sieve and liquid sedimentation	1–100,000	2–100,000	3·4
—	Grimshaw (1958)	Sandstone, blasted	Sieve and liquid sedimentation	2·1–1,000,000	2–100,000	3·4
(o)	Grimshaw (1958)	Airborne dust from blasted sandstone	Thermal precipitator and light microscope	0·5–7	0·5–7	1·6
(p)	McIntyre (1951)	Airborne rock-drilling dust in gold mine	Thermal precipitator and light microscope	0·5–7	0·4–5	2·5
(q)	Talbot (1955)	Airborne rock-drilling dust in gold mine	Thermal precipitator and electron microscope	0·01–3	0·02–3	2·5
(r)	Sichel (1957)	Airborne rock-drilling dust in gold mine	Thermal precipitator and light microscope	0·5–15	0·8–10	2·3
(s)	Tucker (1958)	Airborne rock-drilling dust in gold mine	Thermal precipitator and light microscope	0·5–2	0·2–2	2·25
(t)–(w)	Burdekin and Dawes (1958)	Airborne dust for drilling sandstone, felspar, porphyry, and ganister, and in coal-mine hard-heading.	Thermal precipitator and light microscope	0·5–6·25	1–6·25	2·23 (2·1–2·7)

individual values of γ varied considerably, however, ranging from 1·0 to 3·6 for coal dust and from 1·6 to 3·4 for rock dust. The different methods of making and measuring the dusts seemed to affect the size distribution more than differences in the nature of the material from which the dusts were formed. Moreover, the individual workers chose different mathematical functions to express their results, the choice of function that they considered to give the best fit to their data being either exponential or power law, or a modification or combination of these functions. The method of fracturing the minerals could be expected to influence the size distribution of the particles, but on the other hand the work of HAMILTON and KNIGHT (1958) with coal and rock showed little difference in the size distribution of the debris produced either by crushing, shattering or drilling. It is probable therefore that differences between the reported results of size measurements were due to differences in sampling and evaluation techniques, or to the fact that some workers had attempted to assess the fundamental distribution of a fragmented material whilst others had measured a dust cloud whose distribution may have differed substantially from that of the initially produced dusts, owing to sedimentation or aggregation.

In a recent paper by FAY and ASHFORD (1959) the authors point out that although the basic size distribution of the fine-breakage products of coal may follow a power law, this could be modified in an airborne dust by selective removal of larger particles by gravity settlement, and a sample of the dust cloud could be further changed by the characteristics of the sampling instrument. In their search for a mathematical law to represent the size distribution of coal mine dust samples, these authors examined the fit of their experimental data to the power law, the exponential law, and a form proposed by SICHEL (1957) $dN/dD = A \exp(-b\sqrt{D})$. They concluded that the exponential law agreed at least as well with the bulk of their observations as did the alternatives, and it had the advantage of being more tractable mathematically.

The work described in this paper is an attempt to assess the initial size distribution of airborne dusts produced by abrading coal or rock specimens. The samples were taken with a thermal precipitator and evaluated by optical and electron microscope counting. The size distributions so obtained suggest the possibility of a basic power law distribution of the breakage products, but nevertheless the experimental results are not considered to be a unique property of the dust clouds, but only to be specific to the evaluating system. They are considered, however, to give a fair indication of the pattern of comminution of coal and rock particles from 10 μ down to 0·05 μ, and they can be directly compared with routine dust assessments in British coal mines, where the evaluating system is similar although limited to the optical microscope range.

In previous papers CARTWRIGHT and SKIDMORE (1957a and b) showed that particles of air pollution entering with the ventilation air of coal mines greatly increased the number of particles below 1 μ in the dust clouds underground. The amount of air pollution varied considerably from one mine to another, and from day to day in the same coal mine. The combination of air pollution and dust produced in coal working gave a number-frequency distribution that could be fairly well represented by the two-term exponential expression of WYNN and DAWES (1951). This had the form $dN/dD = A \exp(-\alpha D) + B \exp(-\beta D)$ where the α term defined the size distribution over 1 μ and the β term that below 1 μ. This

function was initially derived from optical counts. Subsequently the electron microscope showed that the part of the size distribution defined by the β term was mainly due to air pollution and that the part defined by the α term was due to dust produced by coal working. The two-term distribution seemed therefore to indicate two distinct components of the dust cloud. There may, however, be more than two appreciably different components in a mine dust cloud, since dusts produced by mining come from many different materials and sources; and the single or multi-term exponential distribution is not necessarily the best general description of dusts found in coal or rock working. For example, HODKINSON (1958) showed that the power law $dN = AD^{-\gamma}dD$ described the distribution quoted by WYNN and DAWES (1951) over a wider particle size range than the exponential law.

Although there is no certainty that air pollution is of relevance to the pneumoconiosis problem, there is little doubt that it introduces complexities into the observed distribution of fine dust particles underground, and various experiments have therefore been made, and are reported in this paper, to determine the size distribution of coal and rock dusts in conditions where air pollution was unlikely to have an appreciable effect on the results. Experiments were also arranged in which the degree of dispersion of the dust could be controlled so that experimental dust clouds could be compared to coal mine dust, where the degree of dispersability varies with working conditions.

2. DUST CHAMBER EXPERIMENTS

2.1 *Experimental details*

Laboratory studies were made of clouds of coal and of other mineral dusts produced in a chamber, with a volume of about $\frac{1}{2}$ m³, in such a way as to simulate the mechanism of dust production in a mine by rubbing, scraping, cutting, or cleaving, the coal or rock. The dusts were not necessarily representative of those that would be produced by impact.

Previous experiments by CARTWRIGHT *et al.* (1956) had shown that air pollution alone, in the vicinity of the Sheffield laboratory, could be as high as 40,000 particles per cm³ in the range $0.04-1.0\,\mu$. Consequently, before the dust clouds were produced, the air in the chamber was cleaned by re-cycling many times through an electrostatic precipitator, and was sampled and checked for freedom from contamination before each test.

Coal and rock specimens were prepared as rods $1\frac{1}{2}$ in. in diameter and mounted in a lathe inside the chamber. The rods were rotated in the lathe at about 200 rev/min, and dust was produced for about 10 sec by cutting with a tungsten carbide tipped lathe tool. In one experiment a steel saw was used in place of the cutting tool, and in another experiment dust was produced by drilling with a tungsten carbide tipped drill. In all experiments the dust was dispersed by a nitrogen jet directed across the edge of the cutting tool, and the air in the chamber was continuously stirred by an electric fan. After cutting, a 10-min dust sample was taken with a thermal precipitator whose sampling head was in the chamber.

During sampling, the fan was switched off, but the air in the chamber was kept in gentle motion by convection currents produced by the heat from a small electric lamp. A correction was applied to the particle counts to allow for the loss of

particles by sedimentation during sampling. The rate of loss of particles of each size range was calculated from the expression

$$dC_x H/dt = -V_x C_x$$

where H was the height of the chamber, C_x the particle concentration, V_x the settling velocity, and $V_x C_x$ the rate of loss, per unit floor area, of particles of size x.

Counts of the thermal precipitator samples were made by comparing particle sizes with the circles of a MAY (1945) graticule. The circles of the graticule increase in diameter in a geometric progression ($\sqrt{2}$ multiplier) and thus have constant logarithmic size intervals, and the direct counts obtained with this graticule give the function $dN/d (\log D)$. Except when otherwise stated, the results of the experiments have been converted to the more commonly used function dN/dD, i.e. the number counts have been divided by range widths to give the relative number of particles per μ range width.

The materials tested in this experiment were:

  (i) a medium rank bituminous coal from the Barnsley seam, Rossington colliery;
  (ii) a sandstone from Darley Dale;
  (iii) a limestone from Buxton.

All the tests were repeated three times and a mean size distribution calculated from counts of at least 100 particles in each of thirteen size classes below 5μ. Counts below 2μ were made with the electron microscope and above 1μ with the optical microscope and the results combined to give a continuous distribution (CARTWRIGHT, 1954; CARTWRIGHT and SKIDMORE, 1953). Both counts were converted to particles per cm³ and a mean value taken for counts in the overlap range of the two instruments. Irregularities in the overall size distribution between 1 and 2μ occurred in several of the results. This was probably because the range is near the limit of the resolving power of optical microscopes, where certain effects may cause false counts to be made, just as at the lower limit of the electron microscope. The resolving power of the electron microscope used for sizing the finer particles was about $0 \cdot 01 \mu$. The precision of counting and sizing, however, was determined by factors other than instrumental resolving power. With particles smaller than $0 \cdot 1 \mu$ the limiting factors were mainly specimen contrast, and contamination which could be introduced at any stage of the experiment. In some samples large counts could have been made of resolvable but unidentifiable points in the images, but with no certainty that the counts were of relevance to the experiment. A value of $0 \cdot 04 \mu$ was considered to be the smallest size at which particles could be classified, by angularity of shape, as consisting of fragmented mineral matter. Even so, the size of $0 \cdot 04 \mu$ must be taken as the extreme limit of the evaluating system and the counts at this size may be too low, for reasons given by HEYWOOD (1954) who stated "There was an interesting similarity between star and particle counting results when the limit of visibility was approached. Early records of microscopical counts, when extended to the extreme limit of resolution, showed a false maximum frequency at a particle size just greater than the lower limit, where it is now known that the numerical frequency for normal dusts increases continuously as the particle size decreases. Star counts made by unaided vision about 300 years ago showed a maximum frequency at about 4th magnitude, the limit of such

vision being about 6th magnitude. With the aid of telescopes it was easily shown that the numerical frequency of stars increased as the magnitude increased, i.e. brightness decreased. The important feature of this comparison was that false effects might be observed if any counting process was worked to the extreme limit of its capabilities."

A maximum frequency was found in most of our results at sizes of the order of $0·1 \mu$. The fall in frequencies below $0·1 \mu$ may be false or may be due to the causes discussed in Section 7. Attention at the present stage is directed to the size distribution of particles of sizes greater than $0·1 \mu$.

2.2 *Results with dusts produced from dry surfaces*

The size distributions of the thermal precipitator samples of dust made in these tests are shown in Fig. 2. Logarithmic scales are used for both frequency and size (equal $\log\sqrt{2}$ increments) and on these scales the function $dN/dD = KD^{-\gamma}$ would be linear since $\log dN/dD = -\gamma \log D + \log K$. The straight lines A and B on the graph represent values of $\gamma = 1·5$ and $\gamma = 2·0$. Since the present discussion concerns only the size distribution of the dusts the concentration factor K is chosen arbitrarily to give convenient spacing between the graphs. The actual concentrations are given in Table 2.

TABLE 2. NUMBER OF PARTICLES PER cm³ BETWEEN 0·9 AND 5·1 μ PRODUCED
IN DUST CHAMBER EXPERIMENTS

Test no.	Coal sawing	Coal turning	Sandstone turning	Limestone turning
1	1800	494	292	2395
2	1416	518	1181	2462
3	1088	784	610	1339

It will be seen from the curves in Fig. 2 that the size distribution of both rock and coal for sizes greater than $0·1 \mu$ are fairly linear on the scales used, and that over a 10:1 size range a power law would give a close approximation to the distribution. Over a 50:1 size range the deviation from a simple power law is shown by a differing γ for three particle size ranges in Table 3.

All the curves in Fig. 2 have much the same slope, and values of γ over the range $0·9–5·1 \mu$ vary only from $1·67$ and $1·84$ for coal, through $1·96$ for sandstone

TABLE 3. VARIATIONS OF SIZE DISTRIBUTION OF DUST CLOUDS EXPRESSED IN TERMS
OF γ IN THE FUNCTION OF $dN = KD^{-\gamma} dD$

Size range in μ	Coal sawing	Coal turning	Sandstone turning	Limestone turning
Overall value (0·11–5·1)	1·57(415)	1·47(280)	1·76(860)	1·89(1400)
Sub-micron range (0·11–0·9)	1·49(23)	1·16(12)	1·60(29)	1·69(35)
Respirable range (0·9–5·1)	1·67(18)	1·84(24)	1·96(30)	2·14(41)

Figures in brackets are numbers of particles at the lower size limit for each particle
at the upper size limit.

to 2·14 for limestone. To consider the values of γ, however, tends to suppress differences. In terms of the relative frequences of 0·9 μ particles, sandstone dusts had 43 per cent more, and limestone 95 per cent more than coal for each particle at 5·1 μ.
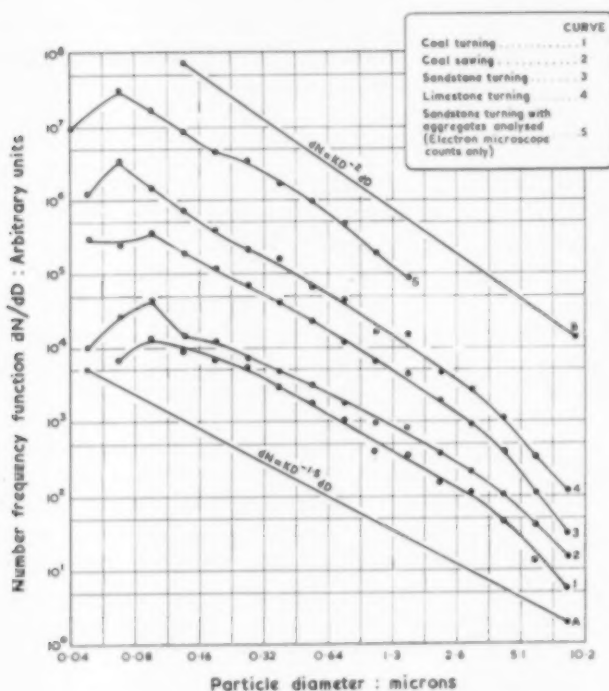
FIG. 2. Size distributions in dust chamber experiments.

The distributions plotted as curves 1–4 in Fig. 2 were from thermal precipitator samples that had been counted on the basis that an apparent cluster of particles was counted as one particle of diameter equal to that of the cluster. Strict observance of this rule ensures that the results are not dependent on the observer's estimation of the components of an aggregate, but errors can arise due to chance overlapping of particles during sampling (IRWIN et al., 1949). In order to estimate the difference between using the above convention and counting the components of an aggregate separately, the electron micrographs of the sandstone dusts were recounted and all "particles" that appeared to consist of two or more aggregated units were classified into their separate components. The result of this analysis is plotted in curve 5 in Fig. 2. The slope of this curve between 0·11 and 0·9 μ is only slightly different from that of the normal count (curve 3). The value of γ is 1·7 when aggregates are resolved, compared with 1·6 with the standard count. Thus, within the resolving power of the electron microscope, and within the observers' ability to discern and to analyse the aggregates, there was little difference between the standard count and the fully resolved count.

These results were obtained with the dust energetically dispersed under laboratory conditions. Before concluding the experiments a few attempts were made to relate these dust clouds to those likely to occur in practical mining conditions, where for various reasons the dust clouds may have a different size distribution to those made in the laboratory. Dust could originate, for example, from wet surfaces and may have a significantly different distribution for this reason. In addition, there would probably be less effective initial dispersion, and a tendency to aggregate which could cause an apparent change of size distribution.

Both cutting and drilling tests were made with dry materials but without the nitrogen jet, so that the dust particles were less effectively dispersed at their source. The size distribution of the dust clouds in these tests were not significantly different from those obtained under conditions of maximum dispersion. It seems therefore that rapid dispersion by the nitrogen jet at the dust source was not a critical factor in determining the size distribution of the dust cloud.

2.3 Results with dusts produced from wet surfaces

It is well known that wet cutting or drilling methods lead to a significant suppression of airborne dust when the dust concentration is judged in terms of total number counts. Our experiments were not designed to produce dust clouds of accurately controlled concentration, and could not be readily adapted to assess the degree of dust suppression. The change of size distribution with wetting could, however, be investigated. Curve 1 of Fig. 3 shows the distribution of the dust cloud produced by coal-cutting while the surface of the coal, which had been previously soaked, was continuously wetted by a drip feed of water with 2 per cent of wetting agent. A further test was made with coal that had been soaked in water for 12 hr prior
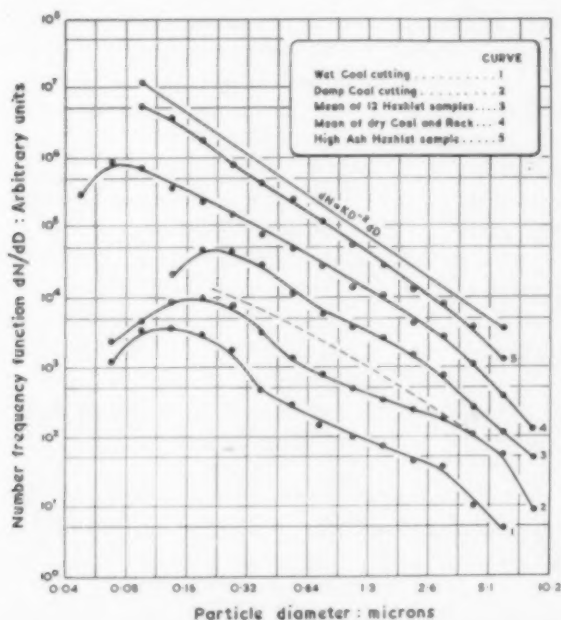
FIG. 3. Size distributions in dust chamber experiments.

to the test but was dry at the surface at the time of cutting. The result is shown in curve 2 and is very similar to that obtained with a fully wetted surface. It seems that the distribution of the dust was related to the water content just below the surface, rather than at the surface itself. The dotted line that has a common point with curve 2 in the range 3·6–5·1 μ represents the distribution of dust previously found with dry coal (curve 1, Fig. 2). The two curves show that if the concentrations are equated at this size there is with wet coal relatively little suppression at 0·2 μ but a reduction to $\frac{1}{3}$ of particle frequency at 1 μ.

These results were obtained with a similar sampling and evaluating system to that generally used in assessing coal-mine samples, and may thus be indicative of the modification of mine-dust distributions resulting from wet working.

2.4 *Results with mine dusts*

The modification of results due to wet working represents only one of the possible ways in which airborne mine dusts could differ from dusts produced in the laboratory. A further difference could be due to aggregation at the high dust concentrations that occur for short periods in mining. Such aggregation could cause a complete removal of some sizes of fine particles when they become attached to larger paticles that settle quickly; alternatively ultra-fine particles could be apparently suppressed simply by attaching themselves to other particles of respirable size.

These possibilities were investigated by an examination of samples collected with a Hexhlet apparatus from two collieries. Six samples from each colliery were dispersed by mulling in nitrocellulose solution and counted optically. From the counts the value of γ was calculated over the range 0·64–3·6 μ. The mean values of γ were 1·92 for colliery B and 1·75 for colliery D. The higher value for colliery B was associated with a higher ash content of 33·5 per cent compared with 24·3 per cent for colliery D. Almost all the samples were taken during coal filling with little rock work in progress, but one was taken while rock ripping and dirt stowing were in progress. An electron microscope count was made of this latter sample, which had an ash content of 46 per cent. A further electron microscope count was made of all twelve samples mixed together.

The combined electron microscope and mean optical counts of all twelve samples is shown in curve 3, Fig. 3, and the electron and optical microscope count of the high ash sample in curve 5, Fig. 3. Curve 4 combines the previous results of the dust chamber experiments with coal and rock to give the equivalent of 50 per cent ash for comparison with the Hexhlet samples. All the results shown in curves 3–5 are nearly linear on the scales used and demonstrate the applicability of the power law to dusts that were either initially well dispersed or redispersed from the bulk sample by a standard laboratory procedure.

There is no indication of any substantial difference between the size distributions of the bulk mine dust and the artificially produced dust.

2.5 *Summary of dust chamber experiments*

The results so far described justify the general conclusion that a simple power-law can, over a certain size range, give a reasonably good description of the size distribution of the fracture products of coal and rock.

The larger the index γ the greater is the preponderance of finer particles in these fracture products. With particle sizes greater than 1 μ, γ had a value of about 2·1

for limestone and sandstone and 1·8 for coal, and for smaller sizes γ was about 20 per cent lower. The reduction of the value of γ for small sizes may be due to a change in the breakage pattern of the minerals tested, but on the other hand may be due to incomplete dispersion of particles of small size. The observed value of γ must be dependent to some extent on the techniques used to measure it, and the methods providing most complete dispersion will result in the highest estimates. Since particles greater than $10\,\mu$ in diameter present few difficulties in dispersion it is reasonable to expect higher values of γ for particulars above this size, and this indeed seems to be the case. GAUDIN (1944) showed results of a number of experiments with ground or crushed minerals in which results fitted a power law with $\gamma = 3$ for sizes mainly greater than $50\,\mu$.

Results more comparable with ours were obtained by HAMILTON and KNIGHT (1958) who gave values of $\gamma = 2\cdot25$ for coal and $3\cdot0$ for rock in experiments in which these materials were shattered by falling weights. The values they gave, however, were mean values from 1 to $100\,\mu$. Their estimate (private communication) of γ in the region of $4\,\mu$ was $1\cdot7$ for coal and $2\cdot1$ for sandstone, i.e. very close to the values found in our experiments. From these results it seems that there may be a real fall in γ of about 2 with reduction of particle size from $100\,\mu$ to $0\cdot1\,\mu$. It would be possible to establish an empirical relationship between γ and particle size and thus to modify the simple power law to a more comprehensive function. Since, however, the available data from μ sizes to mm sizes are derived from such varied techniques as microscopy, sedimentation, and sieving, it is unlikely that such a function would be of either theoretical significance or practical value.

The usefulness of the results of the present experiment lies in the fact that over the respirable size range the value of γ tends to fall slightly down to the smallest sizes examined. Thus if counts are made over a given size range and extrapolated to smaller sizes as a $D^{-\gamma}$ function this will, on the basis of all our results, lead to an overestimation of fine particles and never to an underestimation. The only circumstances in which the fine particles may exceed those predictable by the power law would be when the fine particles were produced by a mechanism other than the larger particles, or if they originated from a different source, e.g. pollution of the ventilation air in coal mines.

3. ATMOSPHERIC POLLUTION AND COAL-MINE DUSTS

The term "atmospheric pollution" will be used to describe the solid matter which is always present in the atmosphere above ground and which can enter with the ventilation air of a coal mine to mingle subsequently with dust produced below ground. Electron microscope studies show that particles of air pollution are mainly spherical, or are chainlike aggregations of spherical units (Figs. 4 and 5). The size distribution of particles of air pollution is a complex function of the distribution of its many components, and can vary considerably from day to day in any one place. In industrial districts most of the pollution comes from smoking chimneys. The smoke is usually quickly scattered by wind and may reduce visibility through the atmosphere but does not in general give the appearance of a dust cloud. This is not because the particles are few in number, but because they are very small. The concentration of particles between $0\cdot9$ and $1\cdot3\,\mu$ may be only 50 particles per cm^3, but between $0\cdot08$ and $0\cdot11\,\mu$ it may be as high as 10,000 particles per cm^3.

Our electron microscope counts of air pollution in coal mines (CARTWRIGHT et al., 1956) have shown the size distribution to be similar to that of air pollution of industrial cities. Over the range $0 \cdot 1$–1 μ it could be approximated to a power law for each sample, although γ ranged from 2 to 2·8 for different samples. A more reliable estimate of the mean distribution of industrial pollution is available from records of air pollution samples taken during the period of the dust chamber experiments. Eighty samples of air pollution above ground were evaluated with the electron microscope, and over the range $0 \cdot 08$–$0 \cdot 64$ μ the mean value of γ was 2.57, with a standard deviation of 0·42 and a standard error of 0·05. The mean value of 2·57 lies within the range of 2–2·8 found in the coal mine investigation.

Since the values of γ found with the artificially produced mineral dust and with air pollution were derived with the same sampling and evaluation system, the effect of the interaction of the two distributions can be assessed in terms of the observed values of γ and the relative concentrations of the two components. If the distribution of air pollution and dust made by coal working had the same value of γ, then the two combined would give a distribution identical with that of either component, and plotted as log frequency against log size would give a straight line with a slope of $-\gamma$. Since the values of γ are different, however, the distribution function would be $dN/dD = AD^{-\gamma_1} + BD^{-\gamma_2}$. The graph of this function would not be linear if plotted on log scales, and the departure from linearity would be greater with increasing differences between γ_1 and γ_2.

If the term $AD^{-\gamma_1}$ represented the mineral dust component of the distribution, and $BD^{-\gamma_2}$ the air pollution component, then the ratio of the frequencies of mineral dust to air pollution at size D_x would be

$$AD_x^{-\gamma_1}/BD_x^{-\gamma_2} = A/B.D_x^{\gamma_2 - \gamma_1}.$$

Since γ_2 was numerically greater than γ_1 in the experiments so far described, the exponent $\gamma_2 - \gamma_1$ would be positive and the ratio of mineral dust to air pollution would become smaller with reducing values of D_x. Thus at sufficiently small values of D_x the distribution would tend to that of air pollution alone. Similarly at sufficiently large values of D_x the mineral dust component would predominate and the frequency distribution would tend to that of mineral dust. The transition region from one value of slope to the other of the combined frequency distribution curve would be centred at a value of D_x such that $A/B.D_x^{\gamma_2 - \gamma_1} = 1$. This value of D_x would depend on the A/B ratio and on the difference between γ_2 and γ_1.

The order of difference shown by our experiments could be represented by taking $\gamma = 1 \cdot 5$ for dust made by coal working and $\gamma = 2 \cdot 6$ for air pollution. The overall distribution to be expected therefore of underground dust in coal mines, including air pollution, can be shown by plotting the function $dN/dD = AD^{-1 \cdot 5} + BD^{-2 \cdot 6}$. If $A = B$, and D is measured in μ, the function would represent the condition where particles of coal or rock dust, and particles of air pollution occurred with equal frequency at 1-μ size. This was approximately the result found in coal mines (CARTWRIGHT and SKIDMORE, 1957a and b). This distribution is plotted in Fig. 6, and a straight line representing a single term power law with $\gamma = 2$ is drawn through the curve. The curve only deviated appreciably from the straight line at its limits, and over a 10:1 size range the deviation is about 10 per cent of the number frequency.

A count of a sample of such a dust cloud would probably have statistical or sizing
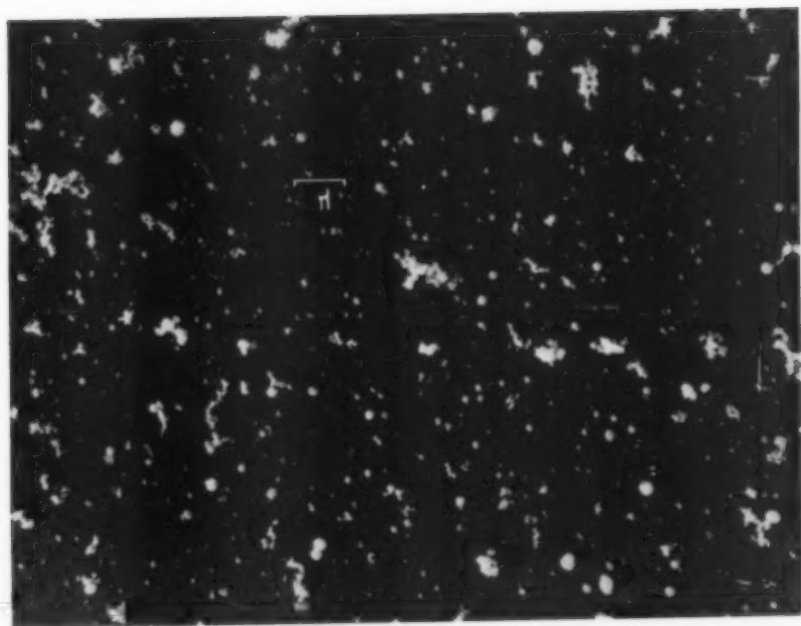
FIG. 4. Particles of air pollution in ventilation intake in a coal mine.
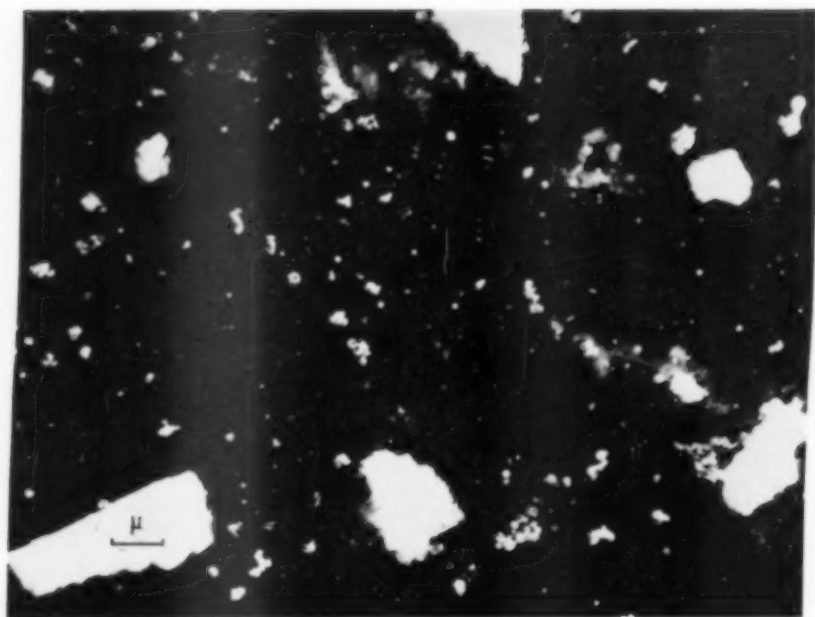
Fig. 5. Air pollution and 2–5 μ dust particles produced in coal working.

errors exceeding 10 per cent, and thus a mixed dust cloud containing components whose γ differed by as much as $1 \cdot 0$ would appear to have the distribution of a simple power law with an experimental scatter of frequencies. There would be no clear evidence of a transition about the point in the size scale where one or other component began to predominate.
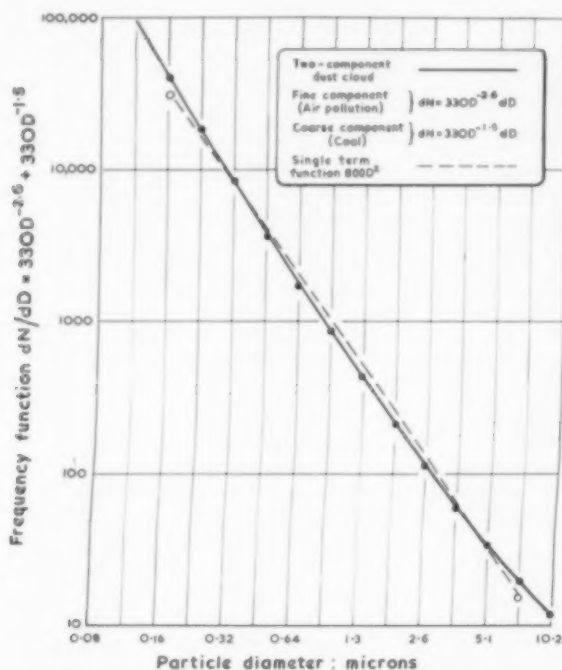
Fig. 6. Distribution of a two-component dust cloud.

It seems that this indeed should be the expected result with coal-mine atmospheres, unless the dust produced in coal working had a markedly different distribution from that of the laboratory produced dust.

4. UNDERGROUND DUST IN COAL MINE

The combined effect of atmospheric pollution and the aggregation of fine particles that may occur in a coal mine can be demonstrated by means of the results previously described by the authors (CARTWRIGHT and SKIDMORE, 1957a and b) of the size-distribution measurements of airborne dusts in South Wales coal-mines. The distributions plotted in Figs. 7 and 8 are the means of six samples in the air intake and six samples in the return airway of an anthracite mine, and of four samples in the air intake and two samples in the return of a bituminous coal mine. The coal face was water infused at each mine.

The mean size distributions of the intake and the return of the anthracite mine are shown in Fig. 7. Our interpretation of this result is as follows. The distribution from 7 to $2 \cdot 6 \mu$ in the return follows a power law with $\gamma = 2 \cdot 2$, and is similar to that of the dust produced in the laboratory. Below $2 \cdot 6 \mu$ the slope gradually falls
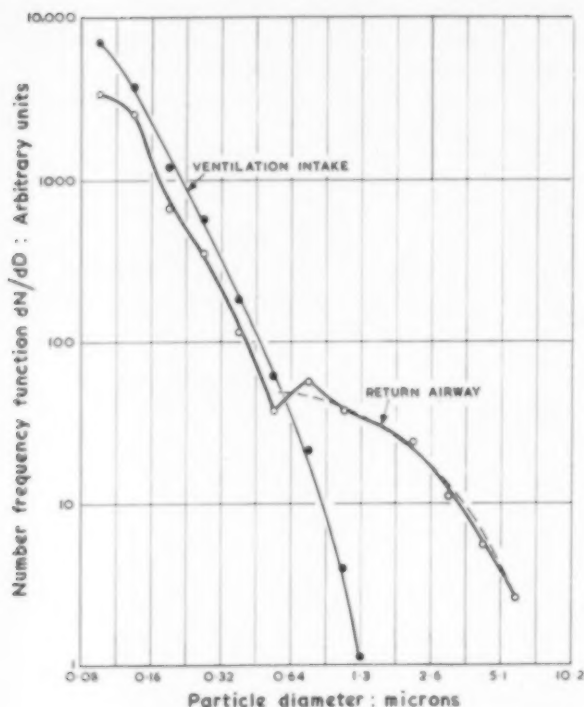
FIG. 7. Size distribution of dust in the ventilation intake and in the return airway
of an anthracite mine.

to zero between 0·9 and 0·64 μ. The degree of suppression of particle concentrations
in the region of 1 μ was rather similar to that found in the laboratory tests with
wet coal (curves 1 and 2, Fig. 3). The distribution over the total range from 0·64
to 7·2 μ is approximately of exponential form, the dotted line through the distribu-
tion over this range representing the function 70 exp ($-0·54$ D). From 0·64 to
0·16 μ the distribution is of the power law form, linear on the logarithmic scales,
and with a slope almost identical with that of the intake air with $\gamma = 2·8$. Visual
inspection of particles smaller than 0·5 μ showed that they were almost all of spher-
ical form, identical in appearance with air pollution particles, and quite different
in form from fragmented mineral particles. It is thus concluded that the component
of the size distribution of the underground dust below 0·64 μ was very largely
air pollution. The concentration of air pollution in this coal mine was well below
the average, presumably because the anthracite, a smokeless fuel, was used for
fires at the pit-head. In terms of mass concentration, the level of pollution was
about 50 μg/m³.

   The size distributions shown in Fig. 8 were from samples in a bituminous coal-
mine when the pollution level was much higher and ranged from 250 to 500 μg/m³.
The distribution in this sample is similar to that of the anthracite mine for particle
sizes over 1·3 μ. Below this size, however, air pollution particles predominate.
The air pollution and mine dust distributions blend to form a fairly linear plot
except for an inflexion between 1·3 and 2·6 μ.
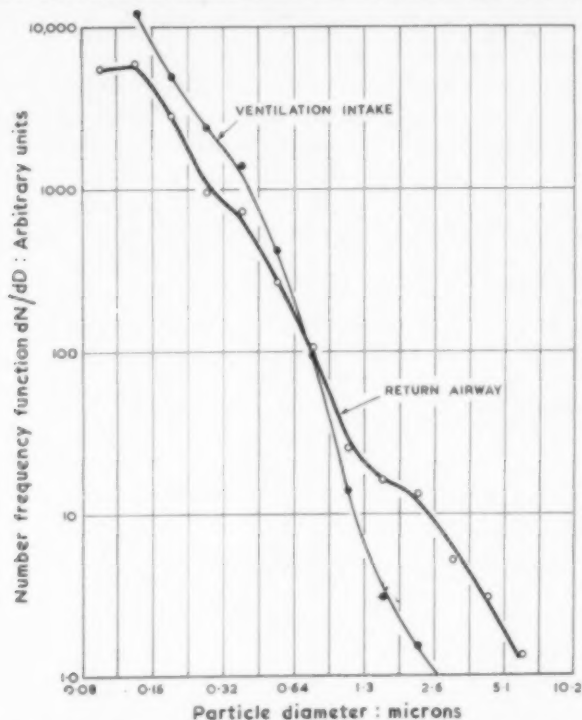
FIG. 8. Size distribution of dust in the ventilation intake and in the return airway
of a bituminous coal mine.

The anthracite and bituminous coal mine results are not dissimilar, except for
the different pollution levels which cause the overall distribution to be characteristic
of air pollution below about 0.6μ in the anthracite mine and below 1.3μ in the
bituminous mine.

The results show that the dust produced by coal working did not appear to
follow the power law found with the laboratory experiments with dry materials.
In the anthracite mine analysis, where the mine-produced dust was clearly distin-
guishable from air pollution down to 0.6μ, the distribution is more adequately
described by an exponential function between 1.0 and 7μ.

The laboratory tests showed that wet working appeared to cause a suppression
of particles about 1μ in size, and this is suggested as a possible cause for the fre-
quencies of particles below 2 or 3μ in the mine dusts being below those predictable
by a power law. The result, however, may be related to the state of aggregation of
the dust rather than to its fundamental distribution. The fully dispersed Hexhlet
dust sample described previously (Section 2.4) had a well-defined power-law
distribution.

5. DRY PERCUSSIVE DRILLING IN A QUARRY HEADING*

Tests were made with a fairly dense cloud of rock dust produced in a location
with a low level of air pollution, in order to avoid as far as possible the complication

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* Heading—a blind tunnel; if in rock, a hard heading.

of air pollution in a dust cloud produced under working conditions. The dust cloud was produced by dry percussive drilling of a block of ganister (quartz content 98 per cent) in a quarry 15 miles outside Sheffield. Before drilling the stone, a test was made of the pollution in the general atmosphere by taking a 500-cm^3 thermal-precipitator sample just outside the heading. During drilling the density of the dust cloud was such that a 30-cm^3 sample gave a satisfactory sample for counting. The results of these tests are shown in Fig. 9. For particle sizes exceeding $0 \cdot 1 \, \mu$ the air pollution concentration was below that of the rock dust by a factor of 10, and had little influence on the result. Below $0 \cdot 1 \, \mu$ the concentration of particles in the rock dust cloud was below that of the general atmosphere. Results of this type have previously been observed (CARTWRIGHT and SKIDMORE, 1957a and b) and are presumably caused by aggregation effects.
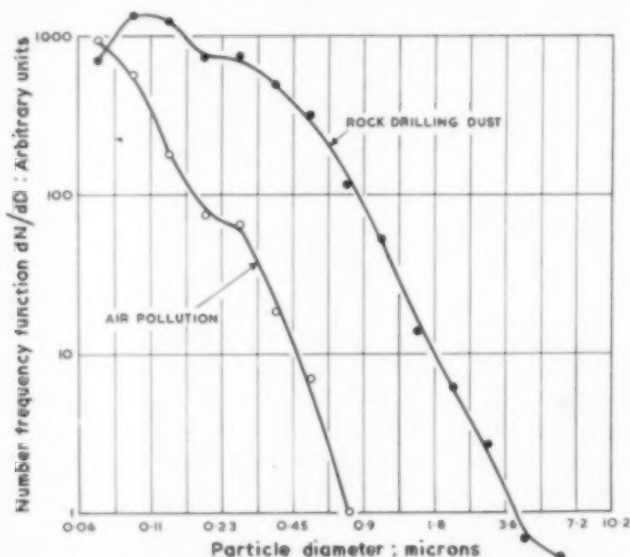
FIG. 9. Size distribution of dust produced by dry percussive drilling in ganister.

The distribution from $0 \cdot 64$ to $5 \cdot 1 \, \mu$ of the rock dust conforms to a power law with $\gamma = 2 \cdot 7$. Below $0 \cdot 64 \, \mu$ the frequencies become progressively lower than those corresponding to the power law.

The value of $2 \cdot 7$ for γ is higher than in any of the laboratory experiments but it is within the range of values calculated by HODKINSON (1958) from the results of BURDEKIN and DAWES (1958) with similar materials and a similar evaluating system. The higher value of γ is not necessarily related to percussive drilling, since the latter authors stated that on statistical test there was no significant difference between their distribution parameters corresponding to rotary or to percussive drilling. It is possible that the difference in the value of γ between this experiment and the laboratory tests is related to the large difference in the scale of the experiments, with a correspondingly large difference in the rates of expenditure of energy in producing the dusts. The result is similar to the laboratory results in the sense that the distribution can be described by a power law over a range of the larger particle sizes, but that the power law is not maintained to very small sizes.

6. DUST PRODUCED BY SHOTFIRING

6.1 *Experimental details*

A series of trials by the NATIONAL COAL BOARD (1957) to test the efficiency of various methods of shotfiring provided the authors with the opportunity for collecting samples for an electron microscope study of mine dust, where the ratio of concentration of air pollution to mine dust was low. This was ensured with normal air pollution levels by taking the samples only during the period when the concentration of shotfiring dust was high. Previous experience had shown that the samples would probably be contaminated by reaction products from the explosive charges, but the magnitude of the effect could not be forecast. On each occasion a sample of the airborne dust in the incoming air was obtained to assess the normal level of air pollution.

Sampling of the shotfiring dust cloud commenced on the arrival of the cloud and continued until it had passed the sampling point. With single-shotfiring each result represented an average value of dust concentration from a number of shots of a series, since the dust from consecutive shots was allowed to accumulate in the thermal precipitator, and the result calculated in accordance with the total volume of air sampled. Average values were thus obtained for all the shots in the rock and for more than fourteen shots fired either singly or in rounds in the coal.

This method was chosen only to provide a comparison of the size distributions of the dust. Comparisons of total dust produced per shot fired are given in the full report of the investigation (NATIONAL COAL BOARD, 1957).

6.1.1. *Shotfiring in coal.* The coal face was 200 yd long, and was divided into two lengths by a maingate; the seam was clean, 4 ft $10\frac{1}{2}$ in. thick, and consisted of a strong bituminous coal with an inherent moisture content of 5 per cent. The face was undercut to a distance of 5 ft 6 in. for each trial and, except for the first (single-shot) trial, the water infusion normally used for dust suppression was suspended prior to and during the actual tests. There was a considerable difference in the quantity of air passing along the two halves of the face, the right-hand side receiving about two and a half times the quantity received by the left-hand side. Dusts from the shots in the two halves of the face were sampled separately, but were allowed to accumulate in the thermal precipitator to give an average result. The conditions of test are given in Table 4.

TABLE 4. FIRING METHODS AND VENTILATION CONDITIONS DURING SHOTFIRING IN COAL

Firing method	Explosive	Airspeed: ft/min		Air quantity: ft³/min	
		Left-hand side	Right-hand side	Left-hand side	Right-hand side
Single shots	Unirend	138	500	4950	15,500
Instantaneous detonators in rounds of six	Unirend	190	740	6120	15,500
Short-delay detonators in rounds of six	Unirend	210	320	4450	10,600
Single shots	Cardox	155	500	4920	15,500
Pulsed infusion single shots	Hydrobel	125	475	4100	10,500

D

The size distributions are plotted in Fig. 10 in a sequence of increasing total mass concentration as calculated from the counts. A standard line, corresponding to the function $dN = KD^{-2.7}\,dD$ (i.e. $\gamma = 2.7$), is drawn on this figure and on Fig. 11 for comparison purposes.
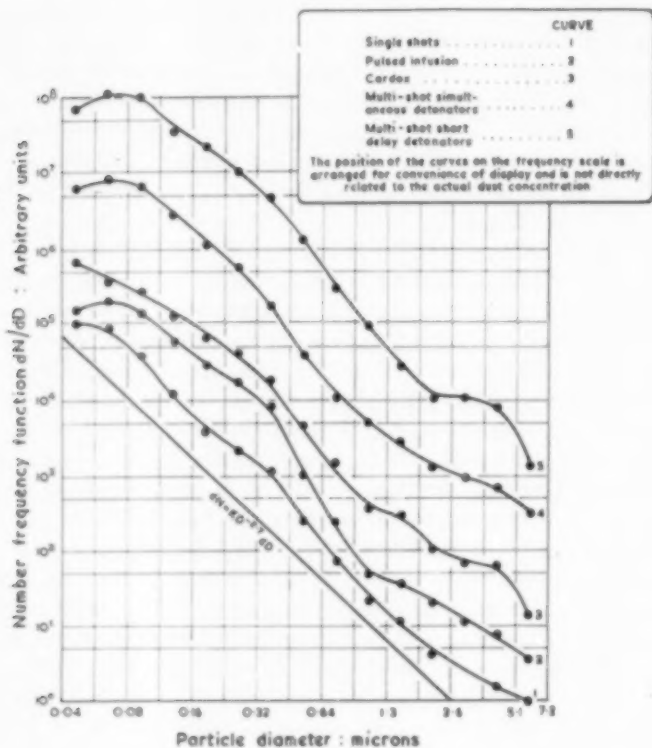
FIG. 10. Shotfiring in coal.

6.1.2 *Shotfiring in a rock ripping.** The rock ripping was 5 ft thick and 13 ft wide, and the rock was sandstone, or sandstone and conglomerate, and was inherently dry. For the first (nine-shot) trial the rip was composed solely of sandstone, but a band of conglomerate appeared across the middle for the second (six-shot) trial. The boreholes were drilled into this band. For the first trial the ventilating air stream passed directly from the main intake under the rip, on the second the air stream was deflected along a cross cut to the left hand side leaving a leaking current under the lip.

The shot-firing cloud was sampled 4 yd along the face from the ripping lip. Only the dust cloud produced by the primary shots or rounds was sampled; the clouds from clearing shots were not sampled. The conditions of test are given in Table 5.

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*Ripping—bringing material down from the roof of a tunnel.

Firing method	Explosive	Airspeed: ft/min (under ripping lip)	Air quantity: ft³/min (along the face)
Nine simultaneous shots	Polar Ajax	300	14,900
Six single shots	Polar Ajax	92	13,550

The size distributions are plotted as curves 1 and 4 in Fig. 11.
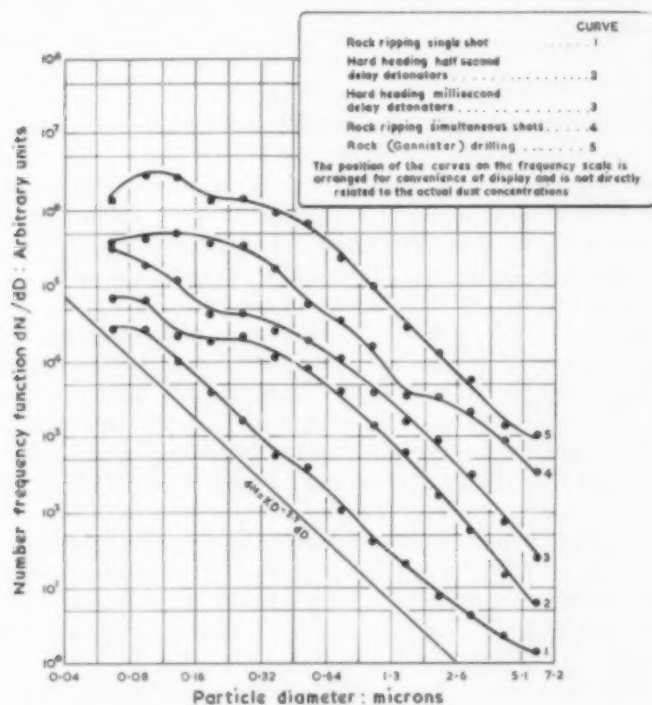
FIG. 11. Shotfiring in rock.

6.1.3. *Shotfiring in a stone drift*.* The roadway was 17 ft × 12 ft and 200 yd long with steel arch supports. The air was drawn from the main intake and supplied to the heading through a ducting to a point near to the face.

For a ½-sec delay detonator trial, two samples were obtained over the periods 0–10 min and 13–22 min from the arrival of the cloud at the sampling point. After these periods it was estimated that there was not sufficient dust to obtain a further useful sample. For millisecond delay detonators only one sample was obtained over the period 0–18 min after the arrival of the cloud at the sampling point. After this time it was not possible to obtain a further sample. The conditions of test are given in Table 6.

* Drift—a tunnel connecting two places, usually at different levels.

TABLE 6. FIRING METHODS AND VENTILATION CONDITIONS DURING SHOTFIRING IN A STONE DRIFT

Firing method	Explosive	Airspeed: ft/min	Air quantity: ft³/min
68 shots with 2-sec delay detonators	Polar Ajax	14·5	2280
58 shots with millisecond delay detonators	Polar Ajax	10·3	1620

The size distributions are plotted as curves 2 and 3 in Fig. 11.

The size distribution of the ganister drilling dust is plotted as curve 5 in Fig. 11 for comparison.

6.2 Discussion of shotfiring results

The air pollution levels in the ventilation supply at the trials were sufficiently low to have only a small influence on the size distribution of the dust after shotfiring. No attempt was made to calculate the actual dust produced in shotfiring by subtracting the counts of the intake cut from those of the shotfiring dust, because previous experiments (CARTWRIGHT and SKIDMORE, 1957a and b) had shown that such a calculation could give false results owing to the complex nature of the interaction of the air pollution and coal mine dusts.

Particles smaller than 0.5μ in the sample taken after shotfiring were mainly rounded and were similar in appearance to particles of air pollution. They were far more numerous, however, than in the intake air and must have been mainly produced in shotfiring. They may have been fume from the explosives, but on the other hand finely ground coal prepared in the laboratory often tends towards a rounded form and thus it was not possible to judge by their shape whether the finer particles were coal or fume.

In curves 1 in Figs. 10 and 11 the distribution function approximates to a power law in the size range of 0.06–7.0μ. There is no clear indication that the distribution has two components, i.e. fume and mineral matter, but it is not impossible that there could be two such components which have blended to give a simple distribution function.

The power law applying down to 0.06μ, however, is only found with samples of low total mass concentration. At higher concentrations the distributions deviate from the power law form with particle sizes below 0.5μ. The general tendency is towards relatively fewer fine particles at higher total concentrations. This effect is shown in Fig. 12, where for each sample the mass of the particles smaller than 0.16μ is expressed as a percentage of the total mass. The results of rock working indicate a continuous curve of falling proportion of fine particles with increasing total concentration. The coal results show a trend in the same direction except that the result with Cardox shows a very low proportion of such fine particles. This is probably because Cardox acts differently from other explosives.

The falling proportion of fine particles with increasing total concentration would appear at first sight to be due to coagulation, but calculations of the magnitude of this effect at the recorded concentration levels did not substantiate this. On the other hand, such losses due to coagulation could have occurred at very high concentration levels soon after the actual firing of the charges.

There is a considerable difference between the proportions of sub-micron particles produced in coal and rock, the mass percentage of ultra-fine particles sometimes being as much as ten times greater with coal. This may be due to the use of different explosives which produce different quantities of fume, but there are other possibilities. It is conceivable that some of the fine particles in the coal experiments were droplets of volatilized and subsequently condensed coal material. This effect would be less likely to occur with rock.
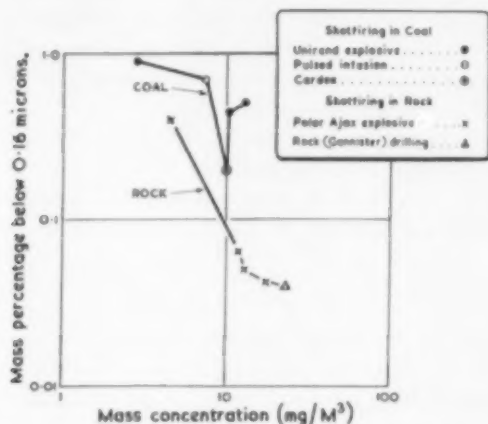
Fig. 12. Mass percentage of particles smaller than 0.16μ in relation to total mass concentration.

The mass percentage of ultra-fine particles in rock ganister drilling is included with the results in Fig. 12, and is in agreement with the trend of the shotfiring results. The size distribution curve of the rock drilling curve 5 in Fig. 11, also resembles that obtained with shotfiring, curve 4, at a similar concentration.

TABLE 7. VALUES OF EXPONENT (γ) OVER THE SIZE RANGE 0.9–7.2μ IN SHOTFIRING AND ROCK DRILLING

Test conditions	Mass concentration in mg/m³	Distribution parameter (γ)
Shotfiring in rock ripping, single shots	4·5	1·97
Shotfiring in hard heading, 0·5 sec delay detonator	11·8	3·20
Shotfiring in hard heading, millisecond delay detonator ..	13·0	2·66
Shotfiring in rock ripping, simultaneous shots	18·0	2·25
Rock drilling	23·0	2·80
Mean value of γ for rock		2·58
Value of γ in laboratory trials with sandstone		1·96
Shotfiring in coal, single shots	2·8	1·8
Shotfiring in coal, pulsed infusion	7·4	1·45
Shotfiring in coal, Cardox	10·0	1·63
Shotfiring in coal, multi-shot, instantaneous detonators ..	10·5	1·55
Shotfiring in coal, short delay detonators	13·0	2·3
Mean value of γ, for coal		1·75
Value of γ in laboratory trials with coal ..		1·76

All the results therefore are consistent in showing that there was a lower proportion of fine particles at the higher level of dust concentration, and at the lowest concentration levels the distribution from 0·06 to 7·0 μ corresponded fairly closely to a power law with $\gamma = 2\cdot7$. This value of γ is very close to that of normal air pollution, but tests of the actual air pollution levels at the time of the experiments showed that the greater part of the fine dust particles must have been produced by shotfiring.

Above 1 μ the particles could be clearly identified in the electron microscope as being of angular shape and for particles of greater than 1 μ diameter the distributions are considered to be representative of the fracture products of rock and coal under these conditions. The distribution of this series of results expressed as the value of γ over the range 0·9–7·2 μ is shown in Table 7.

With shotfiring in coal the mean value of $\gamma = 1\cdot75$ is much the same as that found in the laboratory tests of coal abrasion with $\gamma = 1\cdot76$. In rock working, however, the shotfiring and rock drilling results had a mean value of $\gamma = 2\cdot58$, compared with the laboratory results of 1·96 for sandstone and 2·14 for limestone.

7. CONCLUSIONS

The size distribution of well-dispersed dust produced by fragmentation of dry coal and rock can be conveniently studied by plotting log frequency per unit range width against log particle size. In most experiments the result of this form of plotting is linear over a range of 10:1 and sometimes over a range of 100:1 in particle size.

It is reasonable to suppose that the mode of comminution of a homogeneous solid would follow some such regular pattern, and the results show that over a limited size range the function $D^{-\gamma}$ would describe this pattern. Theoretical considerations suggest that this function could apply down to the size of the structure elements of the fragmented materials, of the order of a few Å units. In the present experiments the continuance of the power law has not been demonstrated below 500 Å (0·05 μ).

Failure to prove the power law below 500 Å could, however, be due to failure of the effective resolving power of the evaluating system. The system could, for example, give a faithful description of the size distribution of aggregates of fine particles but not of the particles themselves. It is probable that even in the absence of any other limiting factors aggregation must inevitably determine the lower limit of apparent particle size. Continuance of the $D^{-\gamma}$ function towards zero size would imply infinite particle numbers and thus infinite aggregation rate. It is possible that aggregation may also explain the general tendency for the slopes of the distribution curves to become smaller below 1 μ.

All our results have shown that frequencies of small particles of fragmented minerals were either equal to, or more commonly less than, the frequencies that would have been predicted by a power law with a value of γ that describes the distribution of larger particles. The only circumstances where larger numbers of fine particles were recorded were when the small particles were probably smoke or fume. On the basis of these results therefore it seems that extrapolation of $D^{-\gamma}$ to small particle sizes would in general lead to an overestimate of their frequencies, and could therefore be considered to give an estimate of the maximum surface or mass likely to be contributed by the smallest particles. The number function

$D^{-\gamma}$ is readily converted to surface or mass, if it is assumed that particle shape does not vary systematically with size. With constant mean shape the surface would be proportional to D^2 and the mass to D^3 for all values of D. Thus the surface function would be $D^{2-\gamma}$ and the mass function $D^{3-\gamma}$. For $\gamma < 3$ the total surface or mass over a range of sizes would be proportional to surface integral $D^{3-\gamma}$ and the mass integral $D^{4-\gamma}$. Thus the mass from size D_1 to D_0 expressed as a percentage of the total mass D_2 to D_0 would be

$$100\left[D^{4-\gamma}\right]_{D_0}^{D_1} \Big/ \left[D^{4-\gamma}\right]_{D_0}^{D_2} .$$

This would be identical with the cumulative mass percentage below size D_1 (down to a limiting size D_0) of any distribution whose logarithmic plot was linear from size D_2 to D_0.

The implications arising from the assumption that values of γ found in our experiments can be applied down to zero particle size are shown in Fig. 13, where
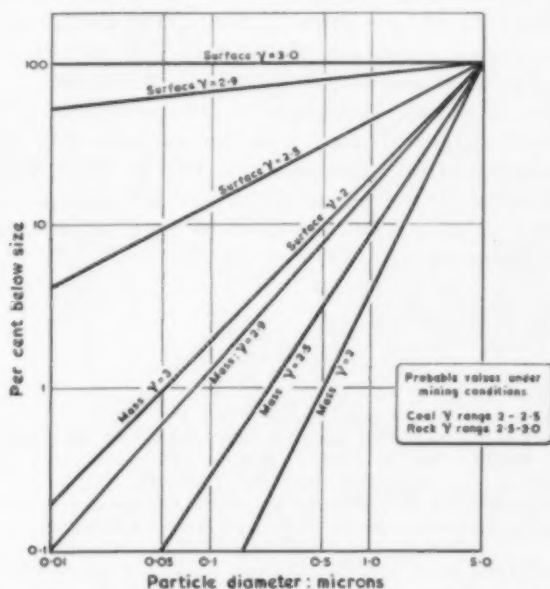
FIG. 13. Surface and mass per cent below size.

surface and mass below size are plotted as percentages of total surface or mass below $5\,\mu$ for values of γ ranging from 2·0 to 3·0. With $\gamma = 2$, roughly that of coal or rock in laboratory tests, there would be 1 per cent mass and 10 per cent surface below $0·5\,\mu$. The estimate of 1 per cent mass below $0·5\,\mu$ would include 0·99 per cent down to $0·05\,\mu$ (from experimental results) and 0·01 per cent from $0·05\,\mu$ to zero size. With $\gamma = 2$ therefore it seems that there would be an insignificant amount by mass and only a small amount by surface represented by sub-micron particles. With $\gamma = 3$, about the highest value found in shotfiring experiments with rock, there would be 10 per cent mass below $0·5\,\mu$, and 1 per cent below $0·05\,\mu$, i.e. a maximum of 9 per cent below $0·5\,\mu$ confirmed by experiment and 1 per cent assumed by

extrapolation. The mass therefore with $\gamma = 3$, would appear to be of moderate proportions in sub-micron sizes.

The surface estimate below size, however, with $\gamma = 3.0$ must be invalid since it would be infinite. This must be so because the surface distribution function $ds/dD = KD^{-1}$ would be equivalent to $dS/d(\log D) = K$, i.e. a constant amount of surface in each of an infinite series of logarithmic steps towards zero size. Clearly the value of $\gamma = 3$ cannot be extended to infinitely small sizes, but on the other hand such values of γ are by no means unusual with particle sizes over 1μ. HODKINSON (1958) quoted six results with γ exceeding 3.0. GAUDIN (1944) discussed the implication of infinite surface with high values of γ taken to zero size and concluded that the power law distribution could not in any event be maintained below a crystallite size of 5Å. HEYWOOD (1944) expressed the view that departure from a power law would begin at much larger sizes than 5Å. Our present experiments suggest that the power-law distribution may not be maintained below about 0.05μ (500Å) and that extrapolation of high values of γ would lead to a gross overestimation of surface of fine particles. A typical example would be the result of a ganister drilling with $\gamma = 2.7$ down to about 0.5μ. The surface below 0.45μ calculated directly from the measured distribution is 9 per cent compared with 50 per cent if the slope was maintained to infinitely small sizes.

It is concluded from all our experiments that extrapolation of an experimentally observed power-law function to sizes below that of the resolving power of the evaluating system will tend to overestimate the finer particles, but that when γ is less than 2.5 the degree of overestimation of mass will be small. With $\gamma = 2.5$, however, the surface may be overestimated by 10 per cent and with γ exceeding 2.5 the surface could be grossly overestimated.

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A FINE GLASS FIBRE PAPER FOR AIR SAMPLING

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(Paper read at a scientific meeting of the society on 15 July 1959)

Abstract—A thin, low-density paper made from very fine glass fibres has recently become available. It combines a low resistance to airflow with high collection efficiency for aerosols. Its advantages compared with filter papers previously used for air sampling for particulate contamination are briefly described with particular reference to the problems of sampling radioactive aerosols.

INTRODUCTION

One of the most direct methods of sampling an aerosol is by aspirating the dust-laden air through a piece of filter paper which retains the particulate material. The volume of air to be sampled to determine the concentration of a contaminating aerosol depends on the method of assessment and the sensitivity required.

The latter is set for radioactive substances by the maximum permissible concentrations in air given in the Recommendations of the International Commission on Radiological Protection (1959). The most restrictive value, which is for plutonium-239, is 2×10^{-12} $\mu c/cm^3$ for 40 hr exposure per week. It follows that 1 m^3 of air will have to be sampled to permit airborne plutonium present at the maximum permissible concentration to be detected, if the efficiency of the equipment used for counting the sample is 30 per cent and if a convenient limit of detection is taken as 1 count per minute.

For operational purposes a sampling time of not more than 10 min is sometimes required, so that a sampling rate of not less than 100 l/min is necessary. If a porous, low-resistance filter paper is used this rate of sampling may be achieved through a 5 cm diameter disc of filter paper (a size which fits standard alpha counting equipment) using a high-speed, multistage, centrifugal fan as used in domestic vacuum-cleaners (see Fig. 1). In addition to low resistance, the choice of filter paper is based on the need for uniformity of texture, absence of pinholes, adequate strength, ease of handling, low substance (g/m^2), smooth finish and adequate retention for the dust being sampled. The first and last criteria are conflicting, and the poor collection efficiency for submicron particles of the low-resistance cellulose paper (Fourstones Paper Mill, Sample A) used for many years at A.E.R.E., has had to be accepted.

FILTER PAPER PERFORMANCE

To improve the performance of fibrous filters made, for example, of cotton, it has been the practice to incorporate finer fibres, and asbestos fibres have been used for many years in the manufacture of efficient filters. More recently very fine glass fibres have been manufactured in the U.S.A., and papers made from them
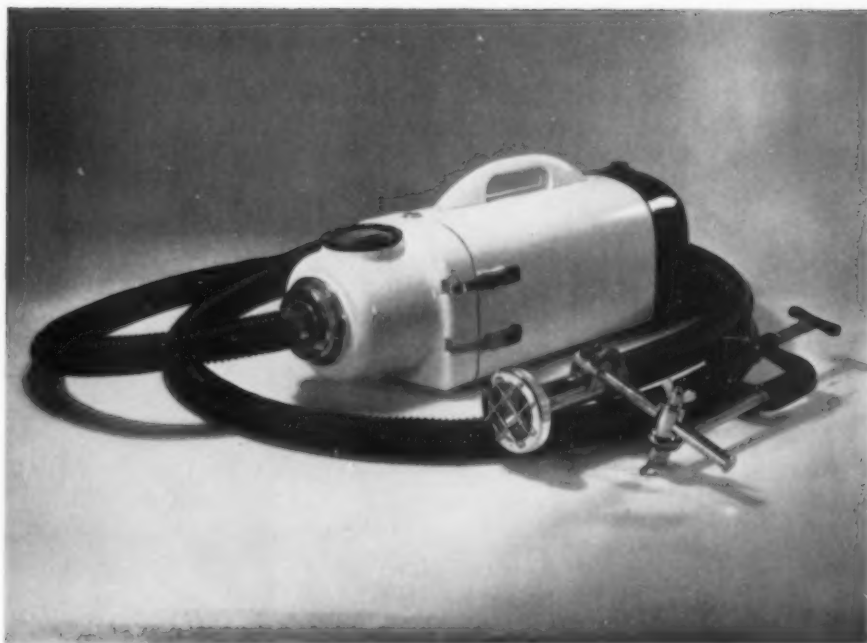
Fig. 1. The dust sampling unit Type 1355.

have been used for the construction of very efficient units for air filtration. Unfortunately the resistance of the papers produced for air filtration has been somewhat too high to make them attractive for use with the vacuum-cleaner air sampling unit. Within the last year, however, some paper has been made in this country from these fibres in the form of a thin uniform sheet of relatively low resistance to air flow and high filtering efficiency which is suitable for use for air sampling. This paper (ref. Whatman GF/A supplied by Messrs. H. Reeve Angel & Co. Ltd.) has been tested at A.E.R.E. Harwell. The results are shown in Table 1 which gives the resistance to air flow of a selection of papers and also the results of measurements of the filtration efficiency of the papers as determined by the Methylene Blue Test (British Standard 2577: 1955).

TABLE 1. RESISTANCE TO AIR FLOW AND AEROSOL PENETRATION THROUGH SELECTED FILTER PAPERS

Paper	Resistance in inches W.G. at a linear air flow of 1 cm/sec	Methylene blue % penetration at a linear air velocity of			
		12·5 cm/sec	25 cm/sec	125 cm/sec	250 cm/sec
Cellulose–Fourstones Sample A	0·1	20	20	10	2
Cellulose–Whatman no. 4	0·2	8	3	1	0·5
Cellulose–asbestos mixture	0·5	0·05	0·06	<0·04*	<0·04*
Membrane–Millipore AA	1·0	<0·01	<0·01	<0·04*	<0·04*
Glass Fibre paper GF/A	0·2	0·04	0·04	0·08	0·06

*For the small test samples used for the tests at high velocity, the test cloud blocks the paper and accurate assessment of penetration is impossible.

The methylene blue test which measures the penetration through the filter of a heterogeneous aerosol with a mass median diameter of about $0·5\,\mu$, gives a direct comparison of the efficiency of filters for a standard fine aerosol, but because of the heterogeneous nature of the test cloud it does not give precise information on the particle size-penetration characteristics.

Calculations of the efficiency of the low-resistance cellulose paper and the glass fibre paper have therefore been made for a range of particle sizes using the formulae of DAVIES (1952) and the results are displayed in Figs. 2 and 3. According to the formulae the index of filtration efficiency is very dependent on the fibre diameter, and calculated figures for the effective diameters of the fibres of the cellulose, asbestos bearing and glass fibre papers are given in Table 2 together with figures for the mean fibre diameter, as measured with a microscope. It is reasonable to associate the good performance of the glass fibre paper with the fineness of the fibres from which it is made.
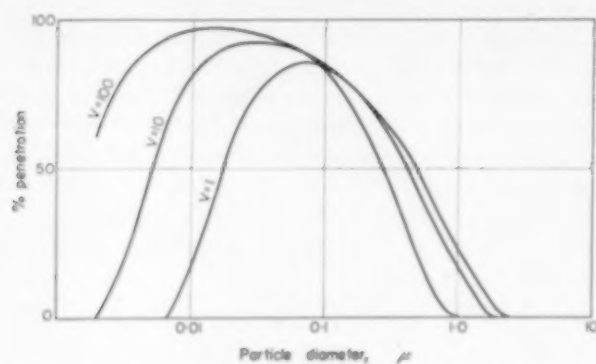
Fig. 2. Calculated performance of Fourstones Sample A paper for particles of unit
density. V is the linear air velocity in cm/sec.
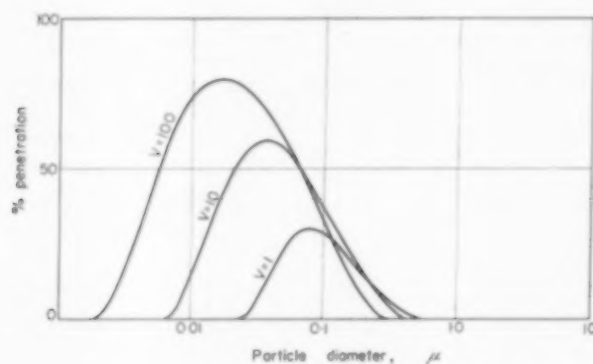
Fig. 3. Calculated performance of Whatman GF/A glass fibre paper for particles of
unit density. V is the linear air velocity in cm/sec.

TABLE 2. FIBRE DIAMETERS

Paper	Mean fibre diameter	
	Measured	Calculated
Cellulose Fourstones Sample A	19μ	15μ
Cellulose–asbestos mixture	—	5·2μ
Glass fibre paper GF/A	0·7μ	1·4μ

INCREASE OF RESISTANCE DURING SAMPLING

It is frequently necessary to take samples for periods of, say, a working day of
eight hours or even longer. In such cases it is not uncommon to find that the
ordinary atmospheric dust collected on the surface of the paper causes an increase
in the resistance sufficient to produce a marked drop in the rate of sampling, es-
pecially if a fan-type sampling device is used.

The rate of increase in the resistance of the glass fibre paper has been found to be less rapid than that of cellulose papers during a series of comparative tests in an inactive laboratory.

The results of one particular test (Fig. 4) show that despite the initial higher resistance of the GF/A paper a larger volume may be sampled over a long period.
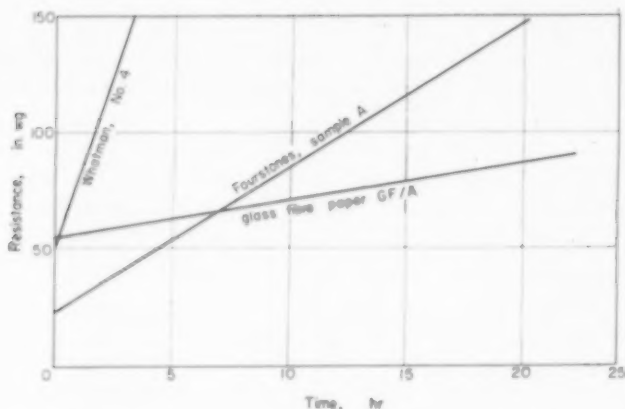
FIG. 4. Increase in resistance to air flow of papers sampling air in an inactive laboratory at a face velocity of 90 cm/sec.

ABSORPTION OF ALPHA PARTICLES IN THE SAMPLE

When sampling with the low-resistance cellulose paper some of the dust penetrates into the depth of the paper. SIMONS (1956) found that for samples taken in laboratories where plutonium was being handled the absorption of alpha particles by the paper fibres necessitated the application of an average correction factor of 1·5.

A consequence of the high filtration efficiency and uniform texture of the glass fibre paper is that a very high proportion of the dust particles are collected on the front surface of the paper, and so no significant absorption of alpha particles occurs. The elimination of the correction factor is equivalent to sampling about 50 per cent more air, and compensates to an appreciable extent for the higher initial resistance to air flow. Figs. 5 and 6 are sections through pieces of low-resistance cellulose and glass fibre papers, through which ordinary air has been sampled to show the different distribution of the dust deposits.

The weight of the glass fibre paper is only some 5 mg/cm^2 against 13 mg/cm^2 for the cellulose paper. If it is assumed that the dust is retained in the first 10 per cent thickness of the glass paper while it is retained in the first 30 per cent thickness of the cellulose paper (see Figs. 5 and 6) then the average absorbing layer is 0·25 mg/cm^2 for the glass and about ten times this value for the cellulose. For alpha particles of 4·5 MeV energy these represent 5 per cent and 50 per cent of the total range respectively.

It is found that it is possible to analyse with the α ray spectrograph α active dust particles directly as collected. Some broadening of the peaks occurs but resolution is quite sufficient to distinguish the common α emitting nuclides.

VARIATION OF WEIGHT WITH HUMIDITY

In sampling aerosols with a conventional filter paper to determine the mass concentration, the variation of weight of the paper with humidity gives rise to troublesome complications. For the glass fibre paper the increase in weight at 100 per cent relative humidity was found to be less than 0·1 per cent of the dry weight compared with a 17 per cent change for a cellulose paper.

TEMPERATURE RESISTANCE

The glass fibre paper seems to be unaffected at a temperature of 500 °C, but at 700 °C melting takes place. Cellulose papers char at temperatures above 200 °C.

CHEMICAL TREATMENT

Experience has shown that where chemical treatment of the collected dust is required, separation of an element, e.g. strontium, has been no more difficult than with conventional filter papers. The fineness of the fibres of the glass paper renders them readily soluble in hydrofluoric acid or by alkali fusion (OSMOND et al., 1959).

SPECTROGRAPHIC ANALYSIS

When selecting a sampling paper for a particular purpose, the possibility of impurities interfering with the analysis must be borne in mind. In addition to the major constituents and impurities found by spectrographic analysis listed in Table 3 the paper has been found to contain 0·0005 per cent beryllium.

TABLE 3. COMPOSITION OF GLASS FIBRE PAPER

Proportion of component	Elements
10%	Si Al
1%−10%	B Na Ba Ca Sr K
0·1%−1%	Mg Zn
0·01%−0·1%	Fe Mn

MICROSCOPIC EXAMINATION ON THE SURFACE OF GLASS FIBRE PAPERS

As the dust sampled is collected on the front surface of the paper, and as the surface is smooth and the fibres are fine, many dusts can be examined directly under the microscope. A drop of immersion oil or Canada balsam on the paper renders the sheet transparent and improves the visibility of the particles. Fig. 7 shows uranium oxide particles at a low magnification. Examination revealed penetration of a few fine particles to a depth of about 30 μ below the surface.

While this method is suitable for coarse dusts and low magnifying power the particles appear hazy at high magnifications with oil immersion. In this case better definition can be obtained by stripping the dust-bearing layer from the front of the sheet. This can be done by painting one side of a cover slip thinly with balsam and pressing it down on the dusty surface of the paper. After about 15 min drying the lower layers of paper may be peeled off, leaving only a thin layer on the cover slip which is then lowered on to a drop of balsam solution on

FIG. 5. Transverse section of Fourstones Sample A paper after sampling air in an inactive laboratory. Thickness of paper 0·35 mm.
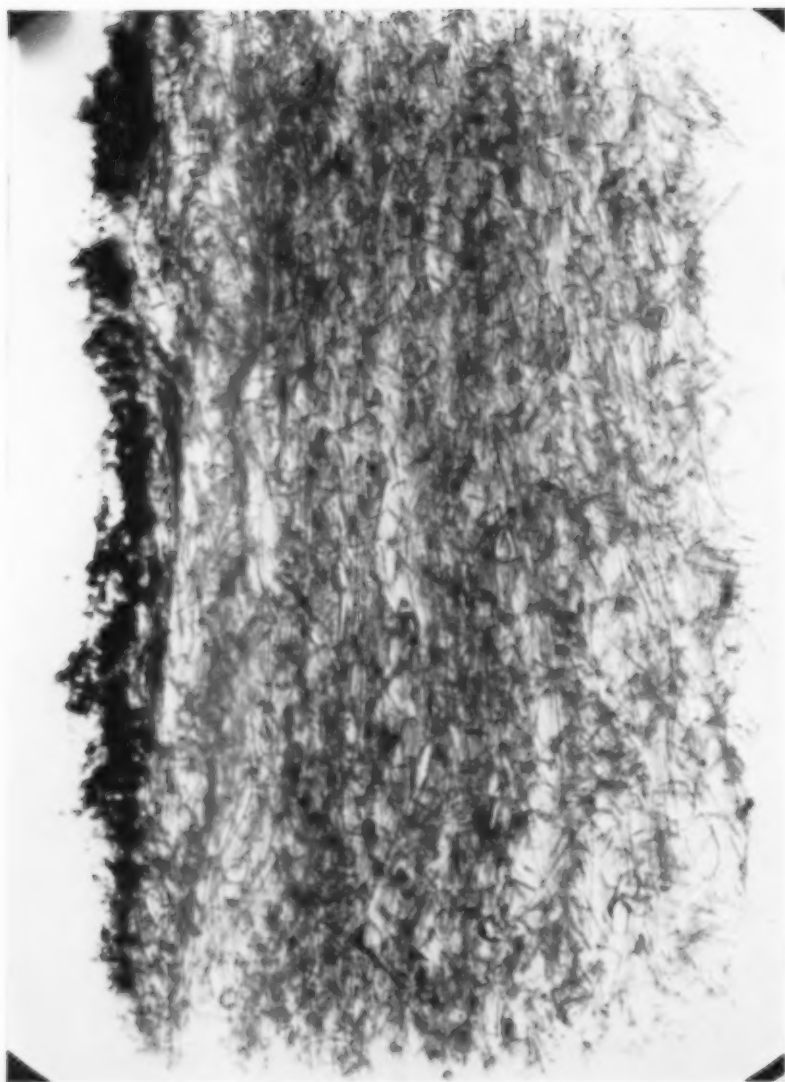
FIG. 6. Transverse section of glass fibre paper GF/A after sampling air in an inactive laboratory. Thickness of paper 0·45 mm.

100 μ
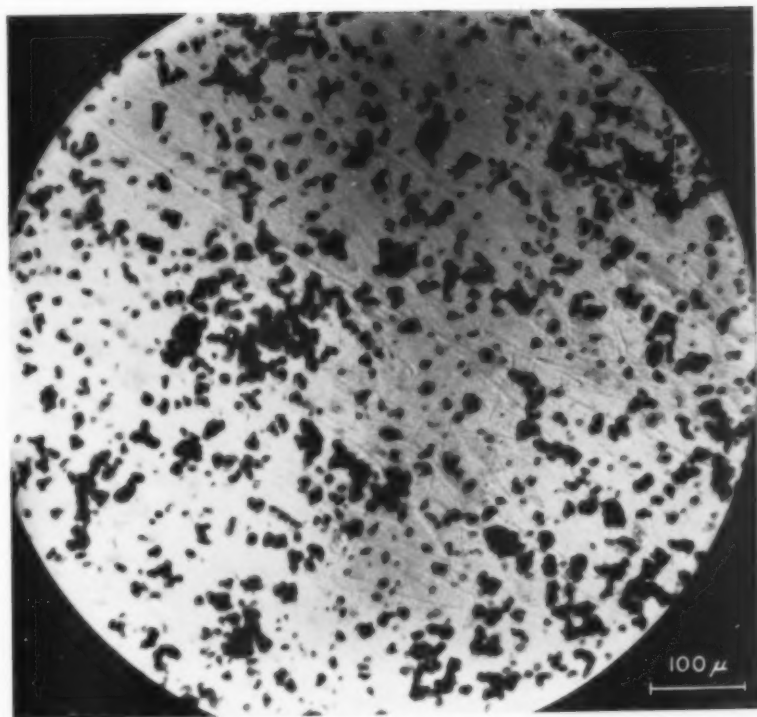
Fɪɢ. 7. Photomicrograph of uranium oxide particles collected on glass fibre paper
GF/A.

a slide. Although a few very fine particles penetrate below the surface of the paper, repetition of this technique on a sample has indicated that less than 5 per cent of those in the $0\cdot2$–$0\cdot5\ \mu$ region are lost. Good resolution is obtained when slides so prepared are examined with oil immersion objectives, but the depth of field is not sufficient to include all particles without some racking up and down of the microscope.

This method has been used for 5 cm diameter discs of paper by mounting under cellophane in Canada balsam. Visibility is quite reasonable, and the method shows promise for isolating radioactive particles by autoradiography particularly if a thinner substance than cellophane (3–4 mg/cm^3) e.g. melinex foil (1 mg/cm^2) can be used as a separator between the autoradiographic film and the filter paper.

HANDLING PROPERTIES

A disadvantage with the glass fibre paper is that it is more flimsy, and it therefore requires greater care in handling than ordinary cellulose papers. The paper has, however, been used without serious difficulty for routine air sampling over a period of several months.

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RECENT DEVELOPMENTS IN OCCUPATIONAL HYGIENE IN JAPAN

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AFTER the Second World War industrial hygiene in Japan was given impetus by the Labour Standards Law which laid down minimum requirements for working conditions. Chapter 5 of this law deals with Safety and Hygiene and article 43 of this chapter refers to industrial hygiene:

"Article 43: Concerning the establishment, or its annex, where the workers are accommodated, the employer must take necessary steps regarding ventilation, lighting, illumination, heating, rest, emergency escapes, cleanliness, and other facilities necessary for the maintenance of the health, good morale, and lives of working people."

Special aspects of industrial hygiene are controlled by regulations on industrial safety and hygiene, and the third volume of these regulations contains provisions for the prevention of occupational diseases. The regulations require employers to appoint health supervisors, who may be medical or non-medical, depending on the number of workers employed. These supervisors concern themselves with matters pertaining to industrial hygiene in the enterprises or offices concerned.

In order to enforce the law a Labour Standards Bureau in the Ministry of Labour, a Labour Standards Office in each prefecture and Labour Standards Inspection Offices within the prefectures were established. Most of the Labour Standards Inspectors graduated from law school, very few of them graduating from medical or technical schools.

In 1955 a special protective law concerning silicosis was enacted. Examinations of workers in dusty industries were carried out from 1955 to 1957; these showed that 11·43 per cent of 34,000 workers had radiological evidence of silicosis, and 1285 workers required medical treatment. From these results and studies on other forms of pneumoconiosis the Silicosis Prevention Council in 1959 prepared the draft of a new law to supplement the shortcomings of the present law.

Physical examination of workers exposed to harmful environments have been carried out at least once a year to comply with the Ordinance on Industrial Hygiene and Safety. In 1956 and 1957, physical examination of workers exposed to sixteen important hazardous environments were carried out on a country-wide scale. The results of this survey are shown in Table 1.

These two surveys showed the incidence of the main occupational diseases in Japan, and the next step will be to carry out the appropriate preventive measures.

Up to now industrial hygiene has been promoted mainly by physicians, but contributions from mechanical engineers, chemical engineers, physicists, chemists and statisticians will be necessary for its future development.

Research on industrial hygiene has been carried out at the Institute for the Science of Labour, the National Institute of Public Health, the Faculty of Medicine, Institutes of Industrial Hygiene established by local authorities, and hygiene sections in plants. Many industrial physicians are members of the Japanese Asscciation of Industrial Health. In 1957 a National Institute of Industrial Health under the control of the Ministry of Labour was established at Kawasaki city near Tokyo, and in 1959 the Japan Association of Industrial Hygiene was created, the members of which are employers and health supervisors in various factories and commercial undertakings.

TABLE 1. RESULTS OF PHYSICAL EXAMINATION OF WORKERS EXPOSED TO 16 HARMFUL AGENTS (1957)

Harmful agents	% of workers who showed abnormal findings	Number of workers who received physical examination
Radiation (exclude U.V. and I.R.)	15·7	4484
U.V. and I.R. radiation	3·9	42,187
Asbestos dust	11·0	1928
Noise	14·5	63,097
Lead	20·9	12,084
Mercury	18·7	1209
Chromium	18·6	1783
Manganese	13·5	725
Yellow phosphorus	0	49
Organophosphate	0·1	875
Sulphur dioxide	11·1	5083
Carbon disulphide	3·5	4123
Benzene	26·6	7929
Benzidine	28·3	60
Nitro and amino compounds of benzene	18·5	930
Halogenated aliphatic hydrocarbon	37·6	588
		Total 147,134

This table shows only the results obtained in 1957.

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A STATE OCCUPATIONAL HYGIENE SERVICE IN CZECHOSLOVAKIA

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There has been a National Health Service in Czechoslovakia, controlled by the Ministry of Health, for more than ten years; it undertakes both treatment and preventive work. A health insurance system is administered by the Revolutionary Trade Union Movement which also supervises industrial safety legislation enacted in 1951. This supervision is carried out by trade union labour inspectors but does not include specialized technical supervision, inspection of mines and industrial hygiene supervision. Legislation covers the general principles of safety supervision at work; for instance, managements must provide and keep in a proper condition all the facilities for ensuring safety and health; they are also required to detect and eliminate causes of injury at work and have a similar responsibility for industrial diseases. Safety technicians, acting in advisory and executive capacities, carry out this work. Employees are required by the same laws to avoid acting in such a way as to threaten their own life or the lives and health of their workmates. The Revolutionary Trade Union Movement supervises safety by means of elected labour inspectors, who are executive members of factory and workshop committees dealing with this type of problem, and labour inspectors who are employed directly by the Revolutionary Trade Union Movement.

Industrial hygiene is not a responsibility of trade union labour inspectors, but is entrusted to the state health administration. The legal aspects of industrial hygiene are included in legislation for hygiene and epidemiological services (1952). This legislation delineates the functions of these services and the executive bodies concerned with their running: it defines the former as follows:

(a) Hygiene of the atmosphere, water, soil, homes, other buildings and public premises.

(b) Hygienic working conditions for workmen, particularly the protection of their health in adverse environments and dangerous processes.

(c) School hygiene.

(d) Nutrition and food hygiene.

(e) Special protective measures against the spread of infectious diseases.

Anybody who is in a position to influence living conditions has the responsibility of taking measures necessary to improve them from the hygiene point of view and of seeking advice from the appropriate official body.

Such bodies are distributed in territorial administrative units; for instance, there are district hygienists who are subject to a regional hygienist, and the whole service is headed by the Chief Hygienist at the Ministry of Health. These officials are mainly concerned with:

(1) Publishing local bye-laws based on the general public health legislation.

(2) Enforcement of regulations, particularly those regarding atmospheric, water and soil pollution, and those specifying satisfactory health standards for food and industrial products.

Planning and building permission for new constructional work has to be obtained from the hygiene authorities. In order to base this work on modern scientific principles there are Hygiene Institutes in each district and region, equipped with laboratories and staffed by physicians, chemists, physicists, biologists, microbiologists and engineers. The regional institutes are particularly well equipped, and are headed by a regional hygienist, assisted by junior hygienists, responsible for the various departments. These include departments of occupational hygiene, communal hygiene, food inspection, school hygiene and epidemiology. Each department has a laboratory section, and experimental animals are available.

Although there is some overlap of general community hygiene and occupational hygiene, reference will be made only to the regulations in respect of the latter.

The purpose of occupational hygiene is to create healthy working conditions, and to protect workers against noxious substances and adverse working environments and processes. All enterprises, including offices and other similar types of work, must take all necessary measures to promote occupational hygiene:

(a) They must ensure that all factories and workplaces are built in healthy areas, and that they are suitably located with regard to the properties, composition and structure of soil and appropriate climatic conditions. Attention must also be paid to adequate supplies of drinking water and sewage disposal.

(b) Working and auxiliary premises must be spacious, properly ventilated with adequate heating and lighting. If necessary, there must be protection against excessive noise, vibrations and dust.

(c) Workplaces, machines, tools and other equipment must be designed with due consideration of work physiology.

(d) Workmen must be protected against the adverse effects of processed material and must be provided with suitable protective clothing and other protective devices.

(e) The layout and methods of work must not be such as to cause excessive fatigue or over-work.

The responsibilities of employees are also defined:

(a) They must adhere to safe and healthy methods of work.

(b) They must wear the protective clothing and protective devices that are provided.

(c) Workplaces and sanitary facilities must be kept in a good condition.

(d) They must participate in training programmes and undergo medical examinations as required.

(e) They must notify their superiors of anything which may be detrimental to health or safety.

Among the regulations published by the Ministry of Health the most important are those regarding:

(1) Hygienic principles incorporated in the design and construction of industrial enterprises.

(2) Catering hygiene.
(3) Industrial hygiene in general.
(4) Dust in factories and mines.

The regulations contain detailed technical requirements, and further similar regulations are to be published. They are supplemented by other regulations concerned with the production and use of poisons and other noxious substances, therapeutic and preventive care in factories, and periodic medical examinations of persons exposed to special hazards.

The occupational hygienist, together with his technical staff, at the regional or district occupational hygiene centre must regularly investigate:

(1) The condition of all available space in work and auxiliary premises; the physical and chemical properties of the atmosphere; lighting, noise, vibration and radiation.

(2) Workplaces, machine tools and other implements as far as work physiology is concerned.

(3) The toxicity and hygiene of products and processed material.

The occupational hygienist advises on the selection, operation and maintenance of protective devices, the method of work, length of working hours, rest periods, night-work, overtime, special problems connected with work of women, juveniles and disabled persons. It is also his duty to arrange medical examinations of workmen exposed to special hazards, and to see that recommendations resulting from these are carried out.

Recommendations resulting from occupational hygiene investigations, some of which are formulated in regulations, are generally concerned with:

(1) Adaptations of working places and machines.

(2) Prevention of excessive heat, particularly radiant heat.

(3) Measures against excessive dust, vapours and gases, e.g. enclosure of processes, exhaust ventilation, replacement of a noxious substance by an innocuous one.

(4) Guarding and other protection on machines.

(5) Defining rules for the use of noxious materials.

(6) The use of protective clothing and other personal protection.

(7) Sending workers suspected of having an occupational disease for medical examination at a hospital department dealing with occupational diseases.

(8) Defining the length of time a worker may be exposed to an adverse environment.

Apart from this routine service the Ministry of Health has two Institutes of Industrial Hygiene and Occupational Diseases which are concerned mainly with research. Senior scientists from these institutes provide methodological guidance for the staff of the hygiene service in the field, and participate in the postgraduate training of these workers at the Institute for Postgraduate Medical Training. In addition, the Institutes of Industrial Hygiene give expert opinion to the Ministry of Health and assist in framing appropriate regulations. They also arbitrate on complicated hygiene problems which cannot be solved by the staff of the hygiene and epidemiological service alone in their regional or district stations.

REVIEW
La Medicina del Lavoro
A new policy

SINCE the inception of the *Annals of Occupational Hygiene* we have received copies of *La Medicina del Lavoro* on an exchange basis. This monthly journal is probably well-known to most of our readers as it is now in its fifty-first volume and has published many outstanding papers on industrial medicine and occupational hygiene to which many of us have referred. The publishers of La Medicina del Lavoro have developed a new policy of publishing papers in English, French and German in addition to Italian. In their own words:

"Experience has shown that first-hand knowledge of Italian papers on industrial health is often limited, amongst foreign research workers, because of language difficulties. The valuable abstracting service carried out by Chemical Abstracts, Bulletin of Hygiene, Excerpta Medica, Zentralblätter, etc., does not provide the reader with all the information necessary to the full utilization of a scientific paper. In order to extend among foreign research workers the knowledge of the contribution of Italian doctors to the research on occupational health, the editor of this journal has decided to accept also papers written in English, French, or German, beginning with the present issue. Papers written in one of the above languages and submitted for publication by foreign authors are also welcomed. It is strongly hoped that this determination will be of aid for the exchange of experiences between Italian and foreign industrial doctors, and that being easier to read, our journal will be found more interesting than in the past. We trust in a favourable reception of our journal."

The first issue of Volume 51 contains papers in English as follows:

A Study of the Action of Silica Particles on Macrophages in Vitro (PERNIS, VIGLIANI and MONACO).

The Histogenesis of Experimental Silicosis I — Methods for the Histological Evaluation of Experimental Induced Dust Lesions (SAFFIOTTI).

A Study of the Mechanism of Acute Hemolytic Anemia from Arsine (PERNIS and MAGISTRETTI).

The journal continues its usual practice of publishing summaries of all their papers in the three languages which have not been used.

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REPORT ON TENTATIVE AMBIENT AIR STANDARDS FOR SULFUR DIOXIDE AND SULFURIC ACID*

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Abstract—This report was prepared in September 1959 at the request of the State of California Department of Public Health for their use in connection with the establishment of Standards of Ambient Air Quality for their state and is published with their kind permission. The full responsibility for the personal opinions thus expressed rests with the author.

The first section presents ten statements about the toxicology of sulfur dioxide and sulfuric acid. Following each statement is a discussion of the literature which has led the author to reach such a conclusion.

The second section presents some values for tentative air standards which were intended as a starting point for consideration and review by the committees concerned.

INTRODUCTION

A FAMILIARITY with the toxicological literature on the oxides of sulfur does not readily yield three-numbered signposts reflecting the relationship of the concentration of these substances in the air and the health, illness, and death of human beings, a situation not unique to this group of pollutants. In addition to the classical toxicological information, however, this literature does contain data relating to the physiological mechanism of action of these substances; this mechanism of action is not unique to this group of compounds.

The various experiments concerning the physiological response resulting from inhalation of defined concentrations of these and other irritants aid in understanding the possible mechanism of damage to that segment of the population known to be the most sensitive to a prolonged increase in the general level of urban pollution. To date, however, they provide no information on how the magnitude of the response in these persons would compare with the response of test subjects presumed to be in good health. They provide data on the response to concentrations of these irritants known to occur from time to time in urban atmospheres. With the exception of a smattering of animal data, these experiments have been limited to periods of an hour or less, thus they provide little useful information on the time course of this response. Furthermore, these experiments have been concerned for the most part with single pollutants or at most a combination of two substances. The data that are available on the simultaneous exposure to more than one substance are sufficient to emphasize the grave importance of the combined action of pollutants, but insufficient as yet to provide a practical quantitative method of evaluating this factor.

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The data from these studies should not be over-extrapolated, which has upon occasion been done, nor should they be discounted on the basis of experience with higher levels of these compounds in the course of industrial operations, with which they are in no way incompatible. Thus, if air pollution standards must be set, these experiments seen in proper perspective can be of assistance. They do not, however, at the present time provide sufficient data to constitute a sound scientific basis for the establishment of such standards.

Having indicated the weaknesses inherent in the foundation of such a procedure, the next step will be to make certain statements about the toxicology of sulfur dioxide and sulfuric acid which apply to the matter under consideration. The statements themselves represent the value judgment of the author, but in each instance the pertinent literature references will be cited. From the considerations thus presented, tentative levels for these two components of the general air pollution will be proposed.

TOXICOLOGY OF SULFUR DIOXIDE AND SULFURIC ACID

(1) *Sulfuric acid is more toxic to animal species than is sulfur dioxide*

Since we are considering here two compounds, it seems helpful at the outset to determine their relative toxicities. Much of this information has been assembled by GREENWALD in his most excellent review of the literature on these sulfur compounds (published in 1954). He has arranged the information in chronological order, according to author, in tables for the two compounds.

For the present purposes, the two compounds have been compared by choosing seven criteria and indicating for each the concentration of the two compounds which would produce the chosen effect. The expression of the concentration in p.p.m. is usually reserved for gases and implies the volume of the gas per million volumes of air. This mode of expression, however, also carries the meaning of mols of compound per million mols of air. Thus, by expressing the sulfuric acid concentrations in this fashion we obtain the same units and also compare the two chemicals on a molar basis. The values for sulfuric acid are also given in mg/m^3, the concentration expression of choice for particulate matter. When the authors have stated the particle size of the acid aerosol, this is indicated, as the particle size affects the toxicity, a point which will be taken up later.

These data, presented in Table 1, indicate that the relative toxicity has been well established.

(2) *"There is no good evidence that either chronic exposure to concentrations below 5 p.p.m. of sulfur dioxide or occasional exposure to higher concentrations, so long as these are not overpowering, have any ill effect upon healthy men."* Quoted from GREENWALD (1954)

Such a conclusion appears entirely valid from an examination of the published reports dealing with industrial exposures to concentrations generally above 5 and most frequently above 10 p.p.m. These will not be discussed or listed individually here as this has been done in a very complete manner by GREENWALD (1954). The over-all impression conveyed by these reports is that such exposures have produced only the mild respiratory symptoms that one would be surprised not to encounter following prolonged exposure to such concentrations of a substance known to irritate mucous membranes.

TABLE 1. RELATIVE TOXICITY OF SULFUR DIOXIDE AND SULFURIC ACID

Criterion of response	Sulfur dioxide		Sulfuric acid		
	Concentration	Ref.	Concentration	Particle size (μ)	Ref.
LC_{50}—guinea pigs	112 p.p.m.—113 hr $C \times T = 12{,}656$ p.p.m.-hr	Weedon et al. (1939)	Young animals (250 g) 5 p.p.m.—8 hr (20 mg/m³) $C \times T = 40$ p.p.m.-hr	1	Amdur et al. (1952)
			14.9 p.p.m.—8 hr (60 mg/m³) $C \times T = 120$ p.p.m.-hr	0.8	Pattle et al. (1956)
			6.8 p.p.m.—8 hr (28 mg/m³) $C \times T = 56$ p.p.m.-hr	2.5	Pattle et al. (1956)
			Older animals (1 kg) 12 p.p.m.—8 hr (30 mg/m³) $C \times T = 126$ p.p.m.-hr	1	Amdur et al. (1952)
Threshold of detection by human subjects	3 p.p.m.	Holmes et al. (1915) Amdur et al. (1952)	0.75 p.p.m. (3 mg/m³)	1	Amdur et al. (1952)
Termed objectionable by human subjects	8-12 p.p.m.	Holmes et al. (1915)	1.25 p.p.m. (5 mg/m³) 0.75 p.p.m. (3-4 mg/m³)	1 —	Amdur et al. (1952) Dorsch (1913)
Recommended threshold limit for industry	5 p.p.m.	Threshold Limit Values for 1958	0.25 p.p.m. (1 mg/m³)	—	Threshold Limit Values for 1958
Amount producing detectable response in human subjects	1 p.p.m.	Amdur et al. (1953) Cullumbine et al. (1955)	0.06-0.12 p.p.m. (0.25-0.5 mg/m³)	1	Amdur et al. (1952)
Amount shown to produce no detectable response in human subjects	0.6 p.p.m.	Amdur and Drinker (1954)	0.03 p.p.m. (0.12 mg/m³)	1	Amdur and Drinker (1954)
Causes a 50% increase in pulmonary flow resistance in guinea pigs exposed 1 hr	55 p.p.m.	Amdur (1957)	0.5 p.p.m. (2 mg/m³) 1.5 p.p.m. (6 mg/m³)	0.8 2.5	Amdur (1958) Amdur (1958)

In animal experiments, earlier literature reported no effect observed in guinea pigs or mice exposed to 25 p.p.m. of sulfur dioxide for over 1000 hr (WEEDON et al., 1939). More recently DALHAMN (1956) and DALHAMN and RHODIN (1956) have published a beautiful piece of experimental work which demonstrates the effect of chronic exposure of rats 6 hr/day for 10 weeks to 10 p.p.m. of sulfur dioxide. They were studying the rate of mucus flow and ciliary beat. In the rats exposed, the rate of mucus flow was reduced and the amount of secretion was increased. The ciliary beat was not affected in these animals although brief exposures of segments of the trachea to this and other irritant gases caused the cessation of ciliary beat in a matter of minutes. The morphological changes which resulted in a decreased mucus flow are beautifully documented. One hopes for further work from these authors along these lines as the sort of information they present could be of great importance. Such changes, which would interfere presumably with the normal mechanisms for the clearance of particulate matter from the lungs could conceivably contribute to the general ill effects of urban pollution. Since the concentration they studied was 10 p.p.m., their data do not modify the statement made earlier by GREENWALD, but do merit consideration in conjunction with it.

(3) *Assuming the particle size to be about 1 μ, chronic exposures to 0.25 mg/m³ of sulfuric acid would be unlikely to have any ill effect upon healthy men*

The literature contains relatively limited data on industrial exposures to sulfuric acid. To the author's knowledge, there exists no such study in which the needed information on particle size of the mist as well as on atmospheric concentration is available. A mist of large particle size, over 5 μ let us say, could be irritating to the nose and throat without producing any serious harm to the individuals so exposed.

Thus, this figure of 0.25 mg/m³ assuming the particle size of major retention in the alveolar portions of the lung was determined by extrapolation from animal data with the application of what in the author's opinion is an appropriate safety factor. At this point we are considering *chronic* effects and *healthy* individuals.

The toxic action of sulfuric acid is bi-phasic: an acute response dependent primarily upon concentration and the chronic effect which is the production of lung damage which is dependent in relatively short exposures (72 hr) upon concentration × time (AMDUR et al., 1952; PATTLE et al., 1956).

The effect on guinea pigs of exposures of up to three months' duration was studied by THOMAS et al. (1958). Of the three particle sizes used—4, 0.9, and 0.6 μ, the medium size was the most toxic. An exposure to 1–2 mg/m³ for three months produced only very slight lung damage in the guinea pigs so exposed. Higher concentrations produced greater effects.

In studies by AMDUR (1958) on the physiological mechanism of the acute response of guinea pigs to sulfuric acid, the lowest concentration used was 2 mg/m³. At the most effective particle size for such exposures to low concentrations (0·8 μ) this concentration did not produce a major alteration in the pulmonary flow resistance, but the response was well above the minimum response that the physiological methods used will detect.

Combining the findings above, it would seem appropriate to apply a safety factor of approximately ten to the 2 mg/m³ concentration studied by these authors. The recommended threshold for industry is 1 mg/m³ for 8 hr/day with no specifications as to particle size (THRESHOLD LIMIT VALUES FOR 1958). Such a level at the variable

particle sizes encountered has presumably resulted in no major harm to workmen. Thus a figure of 0.25 mg/m³ seems reasonable for our present purpose.

(4) *In general the average sulfur dioxide values reported for various urban communities are below* 0.05–0.1 *p.p.m. Corresponding values for sulfuric acid are probably no greater than* 0.02–0.04 *mg/m³*

The sulfur dioxide figures seem well documented. The particular reference upon which this statement is based is a report from Stanford Research Institute by WOHLERS and BELL (1956).

The sulfuric acid values were based on the impression obtained from the statements made by THOMAS *et al.* (1958) and the use of a possible 10 per cent of the sulfur dioxide level. KATZ (1952) working in a smelter area reported an average value of 0.36 mg/m³, but his average sulfur dioxide value was 0.47 p.p.m. so that the former figure would seem too high for application to the general level of urban pollution. The 0.02–0.04 mg/m³ figures seem of the general order of magnitude suggested by the data of the National Air Sampling Network on total sulfates.

These sulfuric acid values are thus open to correction by anyone possessing the data to do so. It is devoutly to be hoped that someone has such data. Measurements of sulfuric acid levels are urgently needed as was emphasized by THOMAS *et al.* (1958).

(5) *The routine levels of these compounds reported for average urban atmospheres probably do not* per se *constitute a public health hazard*

This would seem to follow from a consideration of (2), (3) and (4). This statement does not imply that general pollution of the urban atmosphere does not constitute a serious public health problem; it undoubtedly does. It would be hard, however, on the basis of available toxicological evidence to conclude that these compounds at these levels play a major role in this over-all effect.

PEMBERTON and GOLDBERG (1954) conclude that the death rate from bronchitis shows a better correlation with the sulfur dioxide levels than with the levels of solid matter. Since this dealt with the death rate rather than with the prevalence of the disease, the implication might be that specifically the general levels of sulfur pollution are harmful to those with a diseased state attributable in part at least to the general level of urban pollution. Such data certainly indicate that for the present purposes *Statement* (5) made by a toxicologist, should receive critical review by an epidemiologist.

(6) *The importance of these compounds to the over-all air pollution problem lies mainly in the production of an acute response in sensitive individuals*

None of the papers dealing with the physiological response of human subjects contains any data which would support the idea that these compounds at the levels representing the maximum occurring during acute pollution incidents would harm normal persons (AMDUR *et al.*, 1953; CULLUMBINE *et al.*, 1955; AMDUR *et al.*, 1952; AMDUR and DRINKER, 1954; LAWTHER, 1955; SIM and PATTLE, 1957; FRANK *et al.*, 1959). It should be indicated, however, that these exposures have all been of short duration (10–60 min).

One of these papers (SIM and PATTLE, 1957) contains a description of a developing sensitivity to sulfur dioxide and sulfuric acid mist over a period of 10 months.

The authors were in good health at the commencement of their experiments. One of them developed what he described as "moderately severe but extremely persistent bronchitis" which upon exposure to either of these irritants immediately resulted in "an uncomfortable period of coughing and wheezing". He had never had any previous contact with these compounds. The other author was aware of a personal sensitivity to sulfur dioxide. As the experiments progressed he found the exposures increasingly more irritating. His last exposure was to 39.4 mg/m³ of sulfuric acid mist for 30 min. This resulted in "chest symptoms for the remainder of the exposure day and persistent wheezing for four days following exposure". The concentrations used in these experiments ranged from 1 to 80 p.p.m. sulfur dioxide and from 3 to 39 mg/m³ of sulfuric acid. The experience of these authors certainly suggests that repeated exposures to high concentrations does not produce a tolerance but may instead produce a sensitivity. No such sensitivity was observed during the course of experiments by another group of investigators, but in their case the concentration was never above 15 p.p.m. of sulfur dioxide (FRANK *et al.*, 1959).

In all of the papers relating to exposures of human subjects, some comment is made about particular individuals presumably in normal health who responded more than the other subjects to a given concentration of these irritants. In some cases this was related to the onset of an upper respiratory infection at the time of exposure (SIM and PATTLE, 1957; FRANK *et al.*, 1959). In other cases it was related to a personal history of allergy or was observed in persons who had previously been bothered by polluted fogs (SIM and PATTLE, 1957). In another instance (LAWTHER, 1955) two apparently healthy persons developed audible signs of bronchospasm during the inhalation of 10 p.p.m. sulfur dioxide.

(7) *The physiological response to both these compounds is bronchial constriction. This results in an increase in pulmonary flow-resistance which can be measured quantitatively*

This response to sulfur dioxide has been reported in guinea pigs (AMDUR, 1957), dogs (BALCHUM *et al.*, 1959), and human subjects (CULLUMBINE *et al.*, 1955; LAWTHER, 1955; SIM and PATTLE, 1957; FRANK *et al.*, 1959). A similar response to sulfuric acid has been reported in guinea pigs (AMDUR, 1958) and human subjects (SIM and PATTLE, 1957).

In guinea pigs formaldehyde, acetic acid, and formic acid have also been shown to cause bronchial constriction (AMDUR, 1959a). For the guinea pig these irritants can be arranged in order of potency: sulfuric acid > formic acid > formaldehyde > acetic acid > sulfur dioxide (AMDUR, 1959a). As was indicated in Table 1 sulfuric acid is a more potent irritant to man than sulfur dioxide, but beyond this data do not exist to indicate if this order of potency would be the same in man. Be that as it may, the point needs emphasis that the mechanism of action demonstrable for these compounds is one that they share in common with a variety of other irritants.

In the guinea pig the degree of response can be related quantitatively to the concentration of irritant present (AMDUR, 1957, 1958, 1959a). An extremely small amount of data has recently become available (FRANK *et al.*, 1959) indicating that, using techniques *comparable in principle and sensitivity* to those used with guinea pigs, it is possible to establish such a concentration-response relationship in man. At the present time, however, these data are only sufficient to be useful as an

indicator of a laborious but presumably rewarding pathway for future research.

The paper (SIM and PATTLE, 1957) which presents the maximum number of exposures of human subjects to these compounds (264 ten-min and 330 one-hr exposures to sulfur dioxide and 183 ten-min and 316 one-hr exposures to sulfuric acid) over the widest range of concentrations (1–80 p.p.m. sulfur dioxide and 3–39 mg/m^3 sulfuric acid) is unfortunately written so as to yield the diligent reader the minimum of useful information. The authors state that bronchoconstriction and râles in the chest were observed. They further state that these symptoms were observed less frequently when the dosage of sulfur dioxide was below 800 mg-min/m^3 (which would presumably be on the order of magnitude of 30 p.p.m. for 10 min or 5 p.p.m. for 60 min). When the dosage was above 1330 mg-min/m^3 (which would presumably be on the order of magnitude of 50 p.p.m. for 10 min or 8 p.p.m. for 60 min), the changes were greater. The location of the râles in the chest apparently also varied with the concentration and/or the duration of exposure. In their comment they mention what they term "the absence of any consistent significant changes in respiratory function in these experiments" whereby one is left to conclude that the evidence of bronchial constriction and "high-pitched musical" râles described in their previous pages does not represent such a change in the opinion of these authors.

(8) *The toxicity of sulfur dioxide may be enhanced by the presence of particulate matter. The quantitative application of this knowledge to air pollution is, however, extremely difficult at this stage of understanding*

A few general statements are possibly in order here. This represents one aspect of the potential physical, chemical, and biological interaction resulting from the simultaneous occurrence of a wide variety of pollutants which constitutes probably the major blank area in our knowledge of air pollution toxicology. The toxicology of gas–aerosol mixtures is one area of this problem which, within the past few years, has at least passed from the era of pure speculation (SCHRENK, 1950; VORWALD, 1952; STOKINGER, 1953; HEMESON, 1955) to the era of experimental data (AMDUR, 1957; AMDUR and DRINKER, 1954; FRANK *et al.*, 1959; DAUTREBANDE and CAPPS, 1950; DAUTREBANDE *et al.*, 1951; AMDUR, 1954; LABELLE *et al.*, 1955; GORDIEYEFF, 1956; PATTLE and BURGESS, 1957; GOETZ and TSUNEISHI, 1959; AMDUR, to be published; GOETZ, to be published; AMDUR, 1959b; AMDUR, 1960).

There is pressing need for further research along these lines. In the author's opinion the important factor here is that these experiments be so oriented as to give the maximum information on the *interrelationship* of the toxicological response with the physics and chemistry of the gas–aerosol systems studied. The particular species chosen for this purpose is relatively less important; for example, the potentiation of formaldehyde by inert aerosols has been demonstrated quantitatively in mice (LABELLE *et al.*, 1955), guinea pigs (AMDUR 1959a; AMDUR, to be published) and bacteria (GOETZ and TSUNEISHI, 1959) and qualitatively in man (DAUTREBANDE *et al.*, 1951).

The particle size of the aerosol is important. A synergistic toxic action has been demonstrated for sulfur dioxide and sulfuric acid when the mist particles are 0.8 μ but not when the mist particles are 2.5 μ. With the larger acid particles, the action of the mixture was slightly less than the response to the comparable higher level of sulfur dioxide alone (AMDUR, 1957). An aerosol of sodium chloride which is itself

inert will potentiate the action of sulfur dioxide at a particle size of 0.04 μ. When a comparable loading (10 mg/m³) was given as 2.5 μ particles this effect was not observed (AMDUR, 1957; 1959a).

Two factors would influence the effect of the particle size of an aerosol on the potentiation of an irritant gas: the specific surface area available for association with the irritant gas molecules and the degree of penetration and site and per cent of deposition of the particles in the respiratory tract.

Particles of 5 μ or larger would have less specific surface area and would be retained mainly in the nose and upper portion of the respiratory tract (FINDEISEN, 1935; BROWN et al., 1950). Thus their over-all contribution would be, if anything, to decrease somewhat the toxicity of the associated irritant gas, though the sensation of nasal irritation might be increased.

Particles of 1 μ would present more specific surface area and would penetrate to the peripheral areas of the lungs and be retained in a high percentage (FINDEISEN, 1935; BROWN et al., 1950). Thus particles of this size would in general be expected to potentiate the action of irritant gases.

Particles of 0.4 μ would present a still greater specific surface area which would be presumably somewhat counterbalanced by the fact that this is the size of minimum retention in the respiratory tract (FINDEISEN, 1935; ALTSHULER et al., 1957).

When the particle size reaches the order of magnitude of 0.05 μ, the number of particles and hence the specific surface area becomes a very large number even at moderate aerosol loadings. The pulmonary retention of these particles is on the order of 60 per cent and this retention is alveolar (FINDEISEN, 1935; MORROW and GIBB, 1958). This combination of physical and physiological factors may well mean that these particles have the greatest importance to gas–aerosol toxicity.

The concentration of the aerosol also affects the degree of potentiation of a given gas by a given aerosol. It has been demonstrated for formaldehyde (AMDUR, 1959a; AMDUR, to be published) and also for sulfur dioxide (AMDUR, 1959b; AMDUR, 1960) that when the particle size of a sodium chloride aerosol is held constant at 0·04 μ and the concentration of aerosol is reduced from 10 mg/m³ to 3–4 mg/m³ the degree of potentiation also decreases.

The degree of potentiation of sulfur dioxide is also affected by the chemical composition of the aerosol used. At an aerosol loading of 10 mg/m³ potassium chloride showed a slightly greater potentiating action than did sodium chloride (AMDUR, unpublished data). This may be related to the slightly greater solubility of the gas in solutions of the potassium salt (SEIDELL, 1919). At a loading of 4 mg/m³, manganese chloride exerts a greater potentiating effect than sodium chloride (AMDUR, 1959b). Sensitive spot tests (FEIGEL, 1954; GOETZ, 1958, unpublished) indicated the presence of traces of sulfate when the manganese aerosol was used which could not be found in corresponding tests done when the sodium chloride aerosol was used. This would fit physical chemical studies at higher sulfur dioxide concentrations indicating the catalytic action of manganous ion in converting sulfur dioxide to sulfuric acid (JOHNSTONE and COUGHANOWR, 1958). An inadvertent experiment (AMDUR, unpublished data) is probably also worthy of mention: in the course of exposure of guinea pigs to 0.5 p.p.m. sulfur dioxide, the results were for a brief period quite consistently out of line with the rest of the data. The difficulty was traced to contamination of the chamber air with oil vapor from an ailing pump. Once this condition was corrected, the results lined up with the rest of the data.

There is no clue as to concentration or particle size of the oil mist present, but it was nowhere in the vicinity of the other aerosol concentrations used. On this basis there is adequate data to suggest (though not to prove) that oil mist may have a greater potentiating effect on sulfur dioxide than the inorganic salts already tested.

When one considers the diversity of particle size, composition, and concentration of the aerosols occurring in an urban atmosphere is becomes apparent that, since all of these factors have been shown to affect the degree of potentiation of the sulfur dioxide–aerosol system, the data cited above are not quantitatively applicable to our needs at the moment.

(9) *The response observed to gas–aerosol combinations is not readily reversible*

Another aspect of the gas–aerosol studies in guinea pigs needs comment here. In the case of *all* of the gases (sulfur dioxide, formaldehyde, acetic acid, formic acid) the presence of a sodium chloride aerosol has prolonged the response after the termination of exposure (AMDUR, 1959a; AMDUR, to be published). In the case of sulfur dioxide, this prolonged response has been noted for *all* the aerosols (sodium chloride, potassium chloride, manganese chloride, pump oil) tested (AMDUR, 1959a; 1959b; 1960; unpublished data). The degree of this residual effect is less when the aerosol concentration is less (AMDUR, 1960) and is most likely related to the amount of "irritant" aerosol formed by physical and/or chemical association of the irritant gas with the otherwise inert aerosol.

(10) *Sulfur dioxide and sulfuric acid were contributory but not causitive factors in the acute air pollution disasters in the Meuse Valley, Donora and London*

This would seem to follow logically from all that we have said before. The physiological studies on these and other irritants indicate that the most sensitive individuals would be those with pre-existing respiratory and cardiac disease to whom harm would result from additional stress of an increase in airway resistance. The stagnant air conditions resulting in an increase in both gaseous and particulate pollutants would give the maximum opportunity for the type of interactions we have indicated can alter the degree and duration of response. The cold temperatures prevailing would, on the basis of kinetics, promote gas–aerosol association.

TENTATIVE AIR STANDARDS

Consideration of the toxicological data on these sulfur compounds suggests the possibility for three unrelated sets of standards. These differ in philosophy as in two cases (No. (1) and No. (3)) they represent concentrations which could produce certain effects in sensitive individuals which could be termed adverse, serious, or emergency situations on the basis of the definition given to the author for these terms.* In the third case (No. (2)), these values represent concentrations which in the author's opinion would *not* produce adverse effects in even the sensitive portion of the population.

These standards represent the following situations:

* Adverse: Level at which there will be sensory irritation, damage to vegetation, reduction in visibility, or similar effects. Serious: Level at which there will be alteration of bodily function or which is likely to lead to chronic disease. Emergency: Level at which it is likely that acute sickness or death in sensitive groups of persons will occur.

(1) Standards for occasional transient peaks of an hour or less.

(2) Permissible average levels.

(3) Values pertaining only to reducing type pollution during periods of pro-
longed inversion.

The first two are presumably generally applicable. The third does not apply
to the oxidizing type of pollution characteristic of California.

(1) *Standards for occasional transient peaks of one hour or less*

Effect	Sulfur dioxide	Sulfuric acid
Adverse	5 p.p.m.	1 mg/m^3
Serious	10 p.p.m.	3 mg/m^3
Emergency	20 p.p.m.	5 mg/m^3

There are sufficient data to provide a reasonably sound basis for these particular
values as they indicate a duration of exposure comparable to those used by various
investigators.

A level of 5 p.p.m. sulfur dioxide is termed adverse because (a) It exceeds the
threshold of detection (Holmes *et al.*, 1915; Amdur *et al.*, 1953). In plain terms, it
stinks. (b) It has been termed objectionable by some individuals (Amdur *et al.*,
1953). (c) It has been shown to produce a measurable degree of bronchoconstriction
in human subjects (Frank *et al.*, 1959). (d) It produces a measurable degree of
bronchoconstriction in guinea pigs exposed for one hour (Amdur, 1957; 1959a).
Note that the term used here is "measurable degree" which does not imply a major
alteration. (e) It produced slight symptoms in human subjects exposed for 1 hr
(Sim and Pattle, 1957).

A level of 10 p.p.m. sulfur dioxide is termed serious because: (a) This is irritating
to perfectly healthy individuals unaccustomed to it (Holmes *et al.*, 1915). (b) It
has produced a measurable degree of bronchoconstriction in normal subjects
(Frank *et al.*, 1959) and guinea pigs (Amdur, 1957; 1959a). (c) It has produced
severe discomfort and clinical evidence of bronchospasm in sensitive individuals in
exposures of a few minutes (Lawther, 1955).

A level of 20 p.p.m. sulfur dioxide is termed emergency because: (a) This con-
centration is *very* irritating to the nose, throat, and eyes. (If you doubt this, try it.)
(b) It is well above the minimum levels reported to cause bronchial constriction in
normal test subjects and guinea pigs. (c) The occurrence of such a level in the open
atmosphere even briefly would *per se* indicate the need for drastic control measures
to be taken.

There is a less sound basis for the sulfuric acid levels as there is less usable data
available. The value of 1 mg/m^3 is termed adverse because: (a) It is above the level
shown to produce a respiratory response in normal human subjects (Amdur *et al.*,
1952), although the particular criteria of response in this paper do not furnish the
information most desirable. (b) It has been shown to produce bronchial constriction
in guinea pigs (Amdur, 1958) and the response thus observed is above the threshold
response detectable by the methods used.

The value of 3 mg/m^3 is termed serious because: (a) it is detectable by human
subjects (Amdur *et al.*, 1952). (b) It has been termed objectionable by some (Dorsch,

1913). (c) It is above the minimum level shown to produce bronchial constriction in guinea pigs (AMDUR, 1958).

The value of 5 mg/m³ has been termed emergency because: (a) It produces coughing and irritation in normal individuals (AMDUR et al., 1952). (b) It produces definite respiratory response in 10-min exposures (AMDUR et al., 1952). (c) Such levels have no business in the open atmosphere.

It is altogether possible that the sulfur dioxide values should be lowered on the basis of possible damage to vegetation. This presumably will, if indicated, be done by those reviewers better qualified than the author to evaluate the effects on vegetation.

From the point of view of human toxicology, these values do not, in the author's opinion, contain a very wide margin of safety. If it is understood that these values are intended for occasional (let us say, once or twice a year in a given location) peaks of short duration, this margin of safety is likely adequate.

(2) *Permissible average levels*

> Sulfur dioxide—0.05 p.p.m.
> Sulfuric acid—0.02 mg/m³

The implication here is that, in the author's opinion, the prevalence of these levels on an average basis would not be harmful in any way. No specific justification for this opinion will be given here as this may be best assessed by a perusal of the preceding discussion of the toxicology of these compounds.

These values probably contain a sufficiently wide margin of safety to cover our ignorance of the response of the sensitive individuals who concern us here and our ignorance of the possible potentiating or synergistic effects encountered.

Since this wide margin of safety is present, the above values, commensurate with practical conditions in a given community, could *probably* be doubled, *possibly* tripled, but should *under no circumstances* be multiplied by ten.

It should be pointed out that there exists no "sound scientific basis" for such standards. Hence, this represents the personal opinion of one toxicologist and nothing more.

(3) *Values pertaining ONLY to reducing type pollution during periods of inversion*

Effect	Sulfur dioxide	Sulfuric acid*
Adverse	0.5 p.p.m.	2 mg/m³
Serious	1 p.p.m.	4 mg/m³
Emergency	2 p.p.m.	8 mg/m³

These values are in no way applicable to the oxidizing type of pollution prevalent in California. They are included here because they complete what is, in the author's mind, the relationship of these compounds to air pollution toxicology. It is hoped that their inclusion here will not spread confusion.

In the reducing type of pollution prevalent in Britain and many Eastern cities in this country, the sulfur dioxide and smoke levels are a reasonable index of the general pollution levels prevalent from community to community. Thus from the

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* These values merely indicate the molar equivalent of the stated sulfur dioxide concentration.

experience of the Meuse Valley, London, and Donora it would seem that when a meteorological inversion sets in accompanied by fog and low temperature, a rise in the sulfur dioxide concentration to the levels indicated should call forth appropriate temporary control action until such times as the meteorological conditions alter.

This opinion is predicated upon the fact that these levels may provide a readily measurable index of the possible occurrence of a pollution complex which has occurred several times in the past. Control action in such circumstances should be directed to a reduction in the general level of pollution.

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THE PROBLEMS ASSOCIATED WITH FINE AND OTHER VISUALLY DIFFICULT CONCENTRATED TASKS IN INDUSTRY

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Abstract—The problems associated with fine and other visually difficult tasks in industry are discussed. The factors relating to task analysis, illumination, visual acuity, and performance, together with a brief review of research work in this field, are mentioned. The avoidance of eyestrain is then covered, together with new research in the recording of eye movements, and the prescribing for these tasks, including the use of magnifying aids.

INTRODUCTION

IN MANY branches of industry it is necessary to undertake for continuous periods tasks which are fine or otherwise visually difficult. It is important both for production efficiency and welfare that this work should be done as easily and comfortably as possible. Most managements nowadays realize that this is a worthwhile objective, for with the increasing cost of employing staff and the difficulty in obtaining them, it is essential that they are used to the best advantage.

The problems associated with fine work have become more apparent in recent years because in some industries, for example electronics, there has been a strong tendency towards more and more miniaturization and finer limits. Yet because of normal competitive conditions the actual operation time must often be less than when the task was larger. Therefore if it is possible to realize at an early stage that visual difficulties may arise, to understand their nature and then find a practical solution, all concerned should benefit. A good example is the re-arrangement of a radar control panel (Fig. 1).

For the sake of completeness it would probably be helpful first of all to consider the main factors concerned in a seeing task, how the eyes behave and what are the essentials to make vision as comfortable and efficient as possible. In the field of work study in general much has been done to reduce unnecessary, and therefore unprofitable, effort, but we are not yet really at the stage where we can say that visual effort, and hence fatigue, has been reduced to a minimum.

TASK ANALYSIS

To appreciate the issues involved it is advisable, where possible, to break down a visual task into its component factors. In theory this should be an easy matter, though as often happens in practice, such a tidy approach is not always feasible. However, the basic principles are well worth considering.

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The ability to see a task clearly and easily depends on a number of issues. Assuming a normal condition of the visual mechanism the most important are, the size of the object or the separation between object points, and the difference of brightness or contrast over the task and also between the object and its surround. For example, the inspection of the fine detail of lamp filaments is made easier by using a light background (Fig. 2).
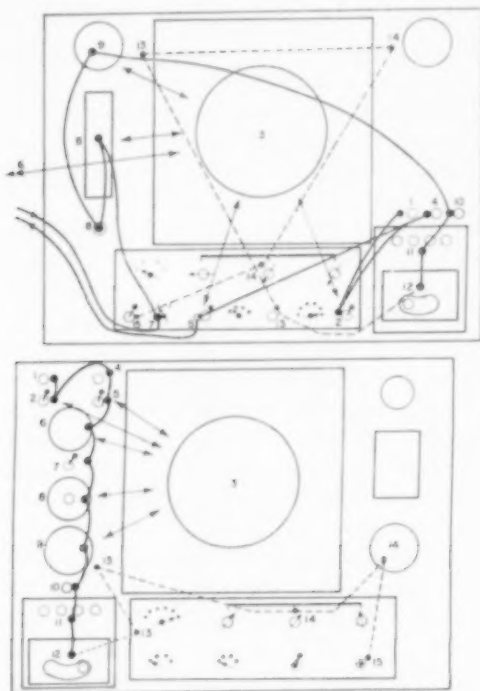
FIG. 1. A radar control panel before and after re-arrangement to reduce unnecessary movement of hands and eyes. (Courtesy E.M.I. Ltd.)

Size and visual acuity

If an object is to be seen in clear detail or two points are to appear as separate they must subtend a visual angle at the eye which for a young adult person of normal vision (6/6 letter at 6 metres) should be at least one minute. For comfort for prolonged periods of visual concentration a larger angle is better. It is possible to increase this visual subtense of the object by bringing it nearer to the eye and therefore making it apparently larger. However, to do so without special optical aids when the task is within about 10 to 12 in. from the eyes is likely to cause discomfort and blurring for all except young people, though here a myopic tendency may be produced in the spot-welding of valve electrodes (Fig. 3). Close inspection is made easier by swinging-in a magnifier.

Illumination, visual acuity and performance

The brightness or luminance of the task depends on the illumination or quantity of light falling on the task and the reflection factors involved, and the greater the

illumination and the greater the brightness contrast between two adjacent areas, within limits, the easier it is to differentiate them as separate. Also as time taken to perceive the detail is of great importance it is necessary also to allow for this, if any recommendations are to be useful.

So that it is possible to see the results of research work in this field in proper perspective and some of the problems involved, a brief review of what has and is being done would probably be helpful.

It is interesting to note that some of the earliest work on the effect of illumination on acuity for the purpose of laying down a standard of lighting was undertaken by Professor COHNS of Breslau University in 1833 using a photometer designed by Professor WEBER for investigating lighting in German schools.

One of the first to investigate experimentally the effect of illumination on visual acuity was LYTHGOE who in the early nineteen-twenties used the Landolt C as his object. He found that there was a definite increase of visual acuity with illumination provided that the brightness of the surround was adequate. In fact FOXWELL and STEVENS (1955) repeated and slightly extended this research. They too found a similar relation between luminance and visual acuity but also that the luminance of the small immediate surround to the visual task, approximately six degrees, had a marked effect especially for higher levels of illumination, but that areas further out were not so important. By changing the luminance of the background correctly they found that there was a relatively large increase of visual acuity up to levels of a hundred foot-lamberts and that the visual acuity was a maximum in this region when the surround brightness was the same as that of the task. Beyond this level, the visual acuity tends to be constant and the surround brightness can be somewhat lower than that of the task. Above the level of one thousand foot-lamberts the visual acuity tends to fall off and the surround brightness need only be one-fifth of the task.

These results are important practically because it means that for tasks which need a high level of illumination, provided the brightness grading for the surrounding region is not too steep, it is adequate and of course cheaper to reduce the area of very high luminance. Secondly there does appear to be a limit to illumination levels which are useful as far as increase of visual acuity is concerned. STYLES (1952) while studying the relation between the brightness of the retinal image and that of the external scene, also came to the conclusion that there was probably an upper limit of brightness of scene of about 1500 foot-lamberts above which there was a visual effect of dancing blue dots.

Luckiesh (1924 onwards)

During the first World War and since, LUCKIESH of the General Electric Company, U.S.A., did extensive research into the effects of illumination on visual acuity and performance. He took as his test object a series of differently spaced parallel bars and compared the task, reading in this case, using his visibility meter, which measured visibility by adjusting the density of a filter until the print became unreadable (a threshold contrast method).

Weston's work

Early in the nineteen-twenties, at a time when scant attention was paid to lighting, WESTON became interested in the effect of lighting and production efficiency and was concerned with a field investigation into the fine visual work of the

weaving industry. Again in 1926, with TAYLOR, he investigated illumination and efficiency for the difficult and concentrated visual task of hand type setting. He found that the rate of performance increased as the logarithm of illumination, up to twenty-five lumens per square foot, provided the surround brightness was high enough.

In 1935 WESTON, sponsored by the Medical Research Council, undertook at the National Physical Laboratory an extensive research project on the relation of illumination and the size of a task, and the efficiency with which it could be perceived, using as his test object the Landolt C. In 1943 he continued his researches on the effect of contrast on the visual acuity and visual performance. He found that we judge contrast approximately by the brightness difference between two adjacent areas and that as the size of the detail decreased so greater contrast was necessary for the same degree of performance. In addition it was found that the general level of illumination, because it determined the state of light adaptation of the eye, had a marked effect on contrast sensitivity.

The results of WESTON's researches were embodied into the British Illuminating Engineering Society's code of lighting practice of 1946. This code was intended as a useful guide to illumination levels for different conditions rather than to give a complete specification. In fact the final recommendations should usually be made by an experienced illumination consultant. It was realized that to achieve the same performance for very small tasks, very high levels of illumination were required and that these may be neither desirable economically nor practically, and therefore a scale of relative performance of 90 per cent was used. As light sources become more efficient, so it is proposed to review the British Code from time to time, and to advise higher levels when they are justified.

Blackwell

In 1950 the American Illuminating Engineering Society and the University of Michigan jointly sponsored Dr. H. R. BLACKWELL in the development of a new system of illumination specification suitable for field use. The results were published in March 1958. His method of approach to task analysis and performance is different from that of earlier workers, and his recommendations called for levels of illumination of about three times those used at present. These new levels concern particularly fine visual tasks.

BLACKWELL felt that it was necessary to design a complete set of laboratory experiments that would relate as near as possible to the factors involved in usual occupational tasks. In his mind, visual performance was not related to quantity and quality of illumination in the way that WESTON suggested when using his Landolt Rings. Rather, brightness discrimination was the most important factor, and then visual acuity when differentiation of spacial pattern was necessary. Accordingly he chose luminous circular test objects which were subject to uniform brightness increment, and employed various contrast ratios and levels of background brightness. He noted the time interval during which an observer could perceive by a difference in contrast that a disk was visible. As five assimilations per second are regarded as possible with unhurried visual scanning and because BLACKWELL felt that most common objects subtend an angle at the eye of between 1–10 minutes, he took as his standard of visual performance the ability to perceive a target of 1 minute, five times a second. He then related illumination levels to give 99 per cent

accuracy under these conditions. He realized that many tasks such as inspection of objects on travelling belts necessitated visual judgement being made when an object was moving, and therefore designed his Field Task Simulator. In this apparatus it was necessary to press a button to reject from a series of disks on a rotating annulus any one where there was an imperfection patch produced by a small local variation in brightness and size.

He then standardized over fifty different types of industrial and commercial tasks to the standard disk by the use of his Visual Task Evaluator. Using the threshold of visibility technique, he found the size of disk which was just visible under the same conditions of contrast as the task. To allow for various differences that would be met in actual working conditions, a field factor of approximately 15 times, or according to the task and other detail, was employed in deciding the illumination levels to be specified for different types of work.

The American Illuminating Engineering Society recommended a new code in June 1958 based on BLACKWELL's work. The levels of illumination ranged from 1 to 10,000 lumens per square foot, and were very much higher than those previously advised, mainly due to the fact that an efficiency of 99 per cent is aimed at for all tasks. Quite a number of these high level schemes have been installed in the United States, though with how much benefit it is probably rather difficult to assess at present. To be successful, very careful design of fitting, lighting scheme and decorations is necessary to obviate troubles due to undesirable glare and heat. The luminous ceiling so far seems to be the easiest method of achieving these levels except for more local installations.

THE DESIGN OF THE VISUAL FIELD FOR EFFICIENCY AND COMFORT

Having reviewed the relation of illumination and contrast when viewing fine tasks, it is now possible to discuss other related work which has been or is being done on other factors related to the visual field.

Light can be used to improve concentration by making the task the brightest part of the visual field, ensuring however that the change of contrast is graded, otherwise discomfort will arise. Also the eye is attracted towards a warm colour as opposed to a cooler colour and therefore the former should be used for an immediate surround to the task where possible. When a considerable amount of concentration is required for a task, a simple screen or wall, decorated in a restful colour should be provided against which the worker can relax the gaze for short intervals. For example, witness the number of people who find it more comfortable to close their eyes momentarily after staring at an object. In some tasks, detail is more easily observed if some directional light is used to show up relief and modelling, for instance, type setting, whereas, for example, for drawing and tracing, shadows at straight edges can be troublesome and shadow-free lighting is often better. (Fig. 4.) ("Shadowless" lighting must, however, be used with care as lack of relief can lessen "clues of position" necessary in some manual operations, e.g. modelling.) Directional lighting will also more readily show up defects, for example, in surface finish. At other times it is necessary to examine the outline of the object or to assess small gaps as in the adjusting of relays. Here greater contrast can be obtained by viewing the object against a light background giving a silhouette effect, thus making the task easier provided the background brightness is no greater than is essential.

Lighting and colour

Where colour discrimination is necessary, or where colour matching is required, when using artificial light sources, attention to the spectral emission of the lamps used is necessary. HELSON (1955) has found that to maximize the difference between certain selected hues in inspection processes greater contrast can be obtained by using a source whose range of colour emission lies between the hues to be discriminated.

The avoidance of glare

Discomfort from glare can be caused by sources of excessive brightness in the field of view, and also by reflection from the work task and its surroundings. The effect of glare is not only to create a condition of visual distraction, and hence mental tension, but also, because of its veiling effect, to reduce the effective contrast over the retina both through its direct action and through the scattering produced by the media of the eye (STYLES, 1952). Various workers, for example HOPKINSON and PETHERIDGE (1957) at the Building Research Station, have found that glare is approximately related directly to the angle subtended by the source at the eye, the square of the source brightness, and inversely as the brightness of the background.

From a practical point of view many cases of reflected glare could be avoided without much difficulty. When the lighting is of necessity directional, a change of position of work or source will prevent the reflected glare from entering the eye. The use of satin or matt finishes of, say, a grey colour for the task surround and for nearby controls will reduce specular reflection from the working surfaces. Where high levels of illumination are required for these fine tasks, glare from lighting fittings can be reduced by keeping the overall contrast between the source and the surroundings as low as possible by the use of diffusers and louvres and also by ensuring that the fitting is viewed against a lightly-decorated background. A good example in which improved lighting has greatly improved productivity is in the new meter room of a large instrument manufacturer (Avo). (Figs. 5 and 6.) One firm (G.E.C.) has, for example, brought out a new fluorescent fitting which is excellent in this respect. By using specially extruded aluminium louvres it is possible to avoid large brightness contrasts and yet direct the light below where it is required.

THE EYES AT WORK

Having made the task as easy as possible to see, it is now necessary to study the behaviour of the eyes and the associated muscular and nervous systems on viewing difficult tasks for long periods. Concentrated visual attention usually necessitates mental attention as well, plus often a state of physical tension. It is not always realized that there is such a close linkage between visual, mental and physical strain, and that the elimination of visual fatigue makes for much greater emotional happiness and physical comfort. One has only to see the improvement in well-being after a bad case of eye strain has been cured to realize this fact.

In the process of seeing there has been no proof as yet of actual retinal fatigue, the exertion in vision being due mainly to the accumulation of the products of metabolism in the ocular muscles. To see a near object clearly, assuming normal binocular vision, it is first necessary for the eyes to converge to a common fixation point and accommodate to bring it into focus. Therefore the position of a task in relation to the eyes is of considerable importance to visual comfort. The nearer the

task the greater the effort of accommodation and convergence required, and the older the subject the more difficult this will be. In general, close working distances usually cause fatigue even for young people when over long periods, and it it generally necessary to relieve accommodation and convergence strain in many cases and essential to do so for the presbyopic older subject.

For example, there was the case of a woman inspector complaining of blurred vision while looking for flaws in die-castings. The firm concerned were already worried about the large amount of faulty work passed. When her husband, the foreman, noticed the improved performance after his wife had been wearing her spectacles, it was arranged for all the staff of the department to have their eyes examined, with very beneficial results.

A very real problem arises when it is desired to investigate, from the point of view of discomfort assessment, the behaviour of the eyes under actual working conditions. It is safe to assume that a competent illumination consultant is now in a position to specify a lighting scheme with due regard to the most suitable type of surround, decorations and other related factors, that will be as visually satisfactory as possible. However, this is only part of the picture, as one is then left to consider the individual variations in the state of the visual mechanism of each particular person concerned. Many people are blessed with a visual set-up which for normal purposes satisfies their requirements perfectly, but when they have to undertake long periods of fine work they become uncomfortable. Witness the housewife who takes up long periods of close work again after the children have become older and is immediately in trouble over eyestrain!

Eyestrain during concentrated vision

When eyestrain is complained of as a result of concentrated effort, there are a number of signs and symptoms which the experienced practitioner can make use of in his assessment of the cause of the discomfort. Concentrated close vision demands considerable accommodation and convergence effort. The former is often accompanied by screwing up of eyes and the latter by frowning. Other people will experience blood-shot eyes as a result of eyestrain, excessive twitching or blinking of the lids. Others complain that the eyes burn, feel as if they are being "pulled", or "hurt at the back of the eyeball". Headaches associated with eyestrain are usually frontal, while occipital headaches are often due to muscular strain resulting from posture. Eyestrain appears to be a neuro-muscular phenomenon but is complicated by the close linkage with mental and physical strain and general health.

It is difficult at this stage to say whether excessive accommodation itself causes discomfort directly from the fatigue of the ciliary muscle, but certainly a sense of mental and physical fatigue results, and there is a falling off in the ability to focus adequately. The extra-ocular muscles definitely appear to be a centre for fatigue and discomfort. Unfortunately the investigation of their actual state of behaviour under working conditions has proved a very difficult matter. Much can be learned by careful questioning on the part of the examiner, as for example, as to what happens when the patient changes fixation during a task: does he lose his place or does the object go double? For instance, a girl working in a glass factory complained of much discomfort and occasional double vision while inspecting for flaws in medicine bottles travelling on a moving belt. Examination showed little refractive error but marked tendency for divergence of the eyes. Comfort was in this case achieved by

FIG. 2. Examination of lamp filaments against a light background. (Courtesy G.E.C. Ltd.)

FIG. 3. Spot-welding of valve electrodes. (Courtesy G.E.C. Ltd.)

FIG. 4. A drawing office with shadowless fluorescent lighting.
(Courtesy G.E.C. Ltd.)

Fig. 5. Meter room of instrument factory with old lighting scheme.
(Courtesy AVO Ltd.)

Fig. 6. Same meter room replanned with new lighting and decorations.
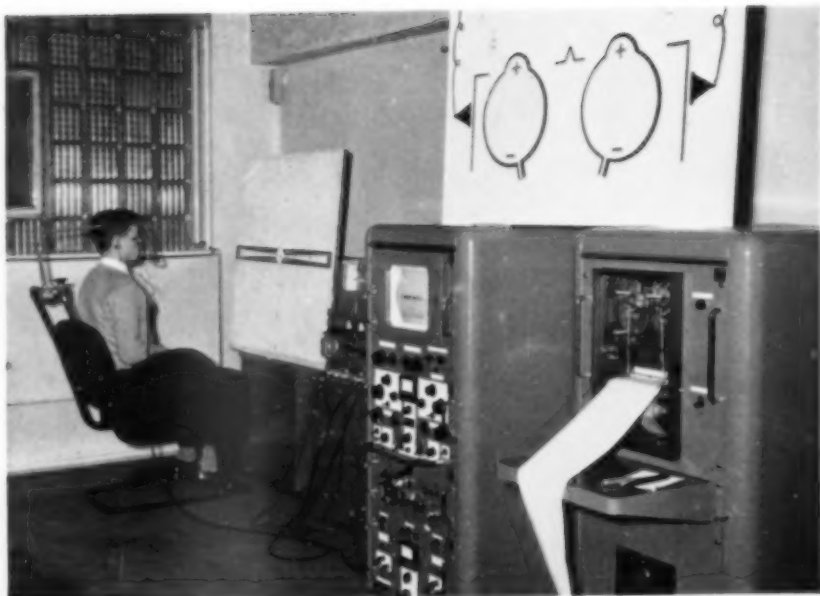
Fig. 7. Electro-Oculograph equipment. (Courtesy E.M.I. Ltd.)

Fig. 8. Original head camera. A lighter and more compact unit is now being developed.
(Courtesy E.M.I. Ltd.)

FIG. 9. The Widefield Magnifier with oil-filled lens and built-in illumination available without book-rest for industrial use.

FIG. 10. The use of watchmakers' glass for inspection of moving-coil meter movement.
(Courtesy AVO Ltd.)

FIG. 11. The use of a monocular microscope for inspection of moving-coil meter bearings.
(Courtesy AVO Ltd.)

Fig. 12. The Zeiss binocular stand microscope with built-in lens turret for giving different magnifications using the same working distance.

prescribing base-in prisms. The experienced practitioner can also learn much by noting all the time during the examination the behaviour of the eyes, particularly if the patient can be seen soon after a spell of work. Existing instruments which measure the state of balance of the extra-ocular muscles, though helpful, can never be a substitute for skilled observation.

Various workers (e.g. LUCKIESH, 1935) have tried to relate ocular strain to nervous muscular tension in the hands and fingers, for example, the degree of frowning or the rate of heartbeats or blinking, with a variable measure of success. What would help very greatly, however, would be an actual record of the movements of the extra-ocular muscles while at work, and a near approach to this end is the recording of the movements of the eyes during a visual task.

The recording of eye movements

Reading is a relatively simple task to investigate in a laboratory and various workers attempted to record the actual movements of the eyes during use (DODGE, CARMICHAEL and DEARBORN, 1948; and others). Two methods have been employed and both have their disadvantages and advantages. The first and earlier method involves recording by cine camera the position of the corneal reflex from a small fixed source while the eye moves. This is a fairly straightforward method, but if head movement is involved the camera must be fitted to the head and an optical reflection system used to pick up the corneal image. It is really necessary for this type of work to use 16 mm film stock to allow for adequate excursions of the eye. The other method, though tried out before the war in the United States, has only recently been developed by SHACKEL (1960) of E.M.I. Electronics Ltd. Use is made of the fact that as the eye rotates a direct current voltage is produced across the cornea and the retina (Fig. 7). The relation between the voltage and rotation is approximately linear and excursions up to 30 degrees can be measured with an accuracy of up to ± 1 degree. The voltage produced is very small, about 15 to 20 micro-volts per degree of rotation. Therefore a high-grain amplifier of the chopper d.c. input type has to be used.

The result can be recorded on a pen chart, a distinct advantage, or on a cathode ray display tube. The effect of stray fields has been kept within small limits. A disadvantage of this method is that the skin beyond the Canthi and the lids on which small suction electrodes have to be attached needs to be prepared by removing a small portion of the outer layer to avoid spurious skin voltages. It is hoped to provide with this equipment a small cine or television camera so that head movements in addition can be recorded (Fig. 8). This method does appear, however, to hold hopes of being able to investigate the action of the extra-ocular muscles under working conditions, particularly as binocular recordings can be made.

Prescribing for seeing of fine tasks

It ought to be stressed first of all that the distance visual acuity recorded on a letter chart is not necessarily an adequate test for near visual performance. Neither is the ability to read for a few seconds an indication that a person will be comfortable for prolonged near vision. If really critical near vision is necessary under these conditions an initial visual screening is well worth while. For example, a firm which is concerned with the production of accurate relief maps from stereoscopic aerial

photographs must have staff with good visual acuity, stereoscopic vision and free-dom from any muscle imbalances which are likely to cause undue fatigue. Training takes several months and a specialized and very thorough visual check-up before finally deciding to employ a candidate has both for the firm and the person con-cerned saved much unnecessary disappointment and wasted effort.

Apart from the correction of astigmatism and other normal refractive errors, when close concentrated tasks are involved, allowance must often be made for the extra accommodation and convergence needed. It is unwise to lay down definite rules, but in general small refractive errors can prove more troublesome than they would otherwise. Such was the case of a girl brazing very small contacts on to a relay leaf. With many people even a small amount of prism base-in, when necessary to relieve convergence, used in conjunction with a spherical addition to reduce accommodative effort in presbyopia often allows a lower addition to be given. There is consequently a greater working range and less blurring of vision beyond this range. When considering corrections for the older worker bifocal and multi-focal lenses are often essential so that tools or controls beyond the working task can be seen clearly. It is often an intermediate range plus the near range which is re-quired, e.g. a draughtsman, and here bifocals with the top portion as an intermediate correction and the lower portion for near vision can be very helpful. Most of these specialized tasks need to be considered individually with an experienced practi-tioner who has an adequate knowledge of the work involved.

The use of magnifying aids

When the visual task is very small it is necessary to consider employing auxiliary magnifying aids. A magnifier produces a virtual enlarged image subtending a larger visual angle at the eye without further accommodative effort than would the object when viewed at the normal distance for near vision of 12 to 14 inches, provided normal near vision spectacles are worn. The degree of magnification employed should not be higher than essential in order to avoid over-restriction of the working area, depth of focus, and, if movement is involved, making the task more difficult through magnification of the movement. Except for casual inspection, a device which allows the use of both eyes is to be preferred, as binocular vision is more comfortable and the stereoscopic vision then possible an asset. It is usually more satisfactory to have an illumination system built into the system so that maximum contrast can be obtained, as normally shadows and lack of adequate intensity from the general room lighting prevent enough light falling on the magnifier.

The simplest type of magnifier is the single lens, preferably with aspheric surfaces for the higher powers to reduce edge distortion. Because of increase of central thickness with power there is an upper limit of about $3 \times$ if a lens is to be large enough to allow binocular viewing. For up to about $2 \times$ oil-filling permits a large and much cheaper lens than solid glass or plastic (for example, the writer's "Wide-field" magnifier (Fig. 9)). The approximate magnification produced by a simple magnifier can be found by dividing the power of the lens in dioptres by four, or dividing the focal length in inches into ten. For monocular use a watchmaker's loupe, in a swinging clip for spectacle-wearers, can be employed when higher magnification is needed (Fig. 10). When higher powers are required binocularly the simple Galilean system, as used in opera glasses, can sometimes be helpful mounted in a spectacle frame, or on a stand, with each system carefully centred for

working distance and user. For magnifications higher than about 6 × a well-designed stand microscope is necessary (Fig. 11). There is one binocular (Fig. 12) available which has a very long working distance and incorporates a lens turret to provide instant changes of magnification while keeping this distance the same.

Where, for example, long periods of critical inspection of small parts are required, profile projection is finding increasing application. The object to be examined, e.g. a small gear wheel, is placed in the path of a projection system, and an enlarged silhouette-image is compared on a translucent screen with an accurate drawing. When using these instruments it is usually necessary to shroud the screen when it is placed against high levels of surround brightness.

CONCLUSION

It has not been possible to cover this subject in all its aspects, but it is hoped that though there is still more research to be undertaken, enough has been said to show that it is possible to use our eyes more efficiently than in the past.

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THE NOISE PROBLEM OF BUILDINGS NEAR AIRPORTS

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INTRODUCTION

AIRCRAFT are the loudest noice source of the present time and the disturbance caused by the noise is very widespread. But serious noise disturbance is mainly confined to the areas around airfields, where the aircraft are low-flying. This area may, in fact, be very extensive—up to 10 or even 15 miles in radius. The coming of the jet engine has greatly aggravated the noise problem because jets are much noisier than piston-engined aircraft of similar size. With the development of the jet airliner, civil airports are becoming the major noise centres of the country. How serious is the problem they create depends upon the density of building (especially of dwellings and offices) within a radius of, say, 10 miles, and particularly on the density along the axis lines of the runways or under the flight paths.

NATURE OF THE NOISE

The designer of a building who wishes to protect the occupants of his building from noise has to know the maximum noise at all frequencies that he must cater for outside his building; if he also knows what noise level is tolerable inside he can calculate the protection required. This may sound a fairly simple matter, apparently involving only the measurement of the noise of typical aircraft at a fixed distance and the calculation therefrom of the noise levels at various other distances. But there are in fact many complications. Some of them are set out below:

(a) The types of aircraft in operation are very numerous, though they can be sorted into certain categories according to the method of propulsion or flight. The main types of aircraft now in use are the piston engine with propeller, the jet, the turbo-prop and the helicopter. In each type there is a range of size or power.

(b) The noise varies with changes in engine power.

(c) The noise of jets is very directional. The maximum noise occurs in the form of a hollow cone to the rear of the aircraft (with the apex at the jet outlet) at an angle of about 35 degrees to the axis of the fuselage (Fig. 1).

(d) Propagation with distance varies at the different frequencies so that the character of the noise changes with distance. The air absorbs the high frequencies, increasingly so as the frequency gets higher, and with ground running of aircraft selective low-frequency absorption by the ground also occurs, perhaps over some types of ground only.

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(e) Propagation, especially from aircraft on the ground or at low level, is affected by wind and weather conditions and by the presence of screens such as intervening buildings.

(f) The rate of climb at take-off power varies with different types of aircraft. This determines the height at various distances and is important close to the airfield, especially under the flight path.

(g) The flight path pattern around the airport may be changed frequently, especially if there are several runways.
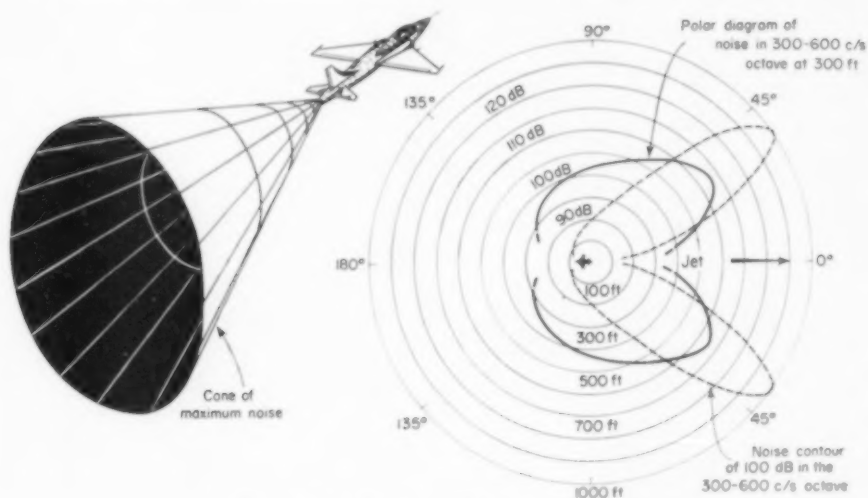
FIG. 1. Directionality of jet aircraft noise.

(h) The effects of a rapidly moving source must be considered, notably the time element or loudness duration of the individual noises.

(j) The frequency of occurrence of different loudnesses of the noise has to be taken into account.

Knowledge on all these factors is gradually being accumulated. As an early example of noise measurement of aircraft in flight the Building Research Station has measured the noise levels of different types of civil aircraft 125 ft overhead at take-off power, and the results have been published (PARKIN and PURKIS, 1954). Some examples of aircraft noise spectra taken partly from these results are given in Fig. 2. But the noise spectrum is only the first step in assessing the possible nuisance around airports and all the factors listed above must be considered. Aircraft noise will always be a difficult problem to get to grips with because of the large number of variables; when dealing with such variable problems it is not easy to generalize.

An important feature of the problem is that aircraft are increasing all the time in size and power and therefore in noise also. Fig. 3 shows how the noise of piston-engine aircraft is related to weight or horse-power. The noise of jet engines also corresponds to power, but the power to weight ratio is higher. A great deal of work is being done by the jet engine manufacturers on the reduction of engine noise in

flight by means of jet-outlet mufflers, but these mufflers sacrifice power in achieving noise reduction—almost *pro rata*. A very optimistic view is that the design of silencers for aircraft in flight may possibly keep pace with the general increase in power of commercial aircraft; there seems to be little hope of a net reduction of noise. But an interesting feature of the flight mufflers now in use by the Boeing jet airliners is that they are designed to transmute the sound energy from low-frequency to high-frequency; this makes them noisier when close, because the ear is more sensitive at high frequencies, but less noisy beyond a certain distance because the air absorbs the high frequencies preferentially.
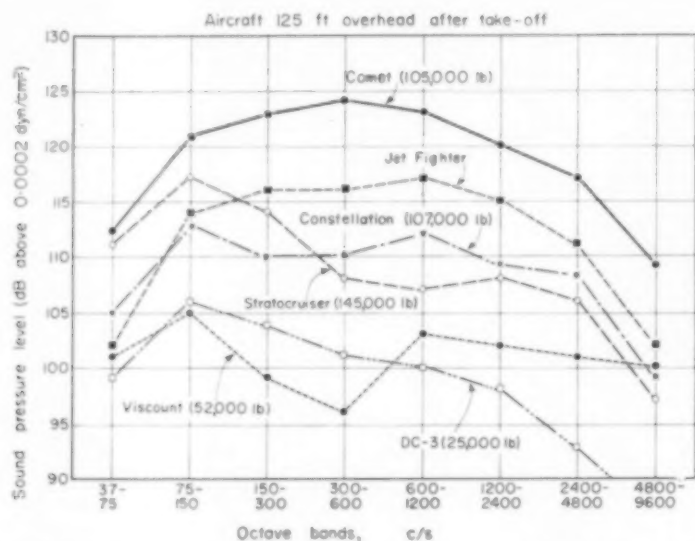
FIG. 2. Some noise spectra of aircraft 125 ft overhead at full power.
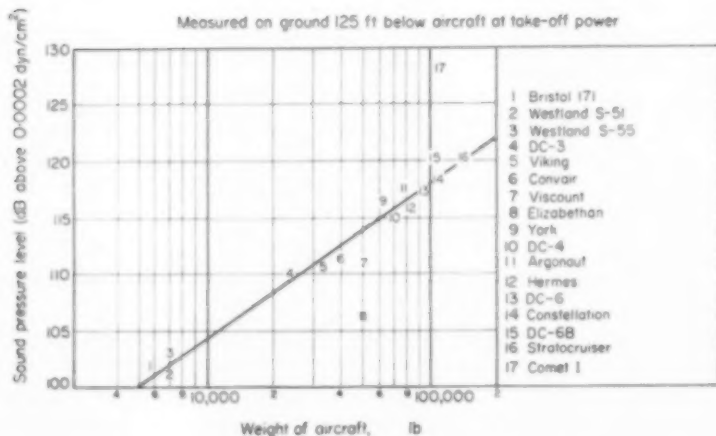
FIG. 3. Noise levels of aircraft in relation to their weight.

AIRPORT NOISE PATTERN

The distribution of noise in the locality of the airport is dependent on the flight pattern, the angle of take-off and the location of the aircraft maintenance areas. Most airports have at least two runways, the layout of which is based on the prevailing wind direction, the ground formation and the surrounding land use. Busy airports will have pairs of parallel runways for taking off and landing. The choice of runway in use depends on the wind and weather conditions, especially for propeller aircraft, but the direction of the prevailing wind usually dictates the use of a particular runway and direction of flight for a major part of the time. Fig. 4 gives a
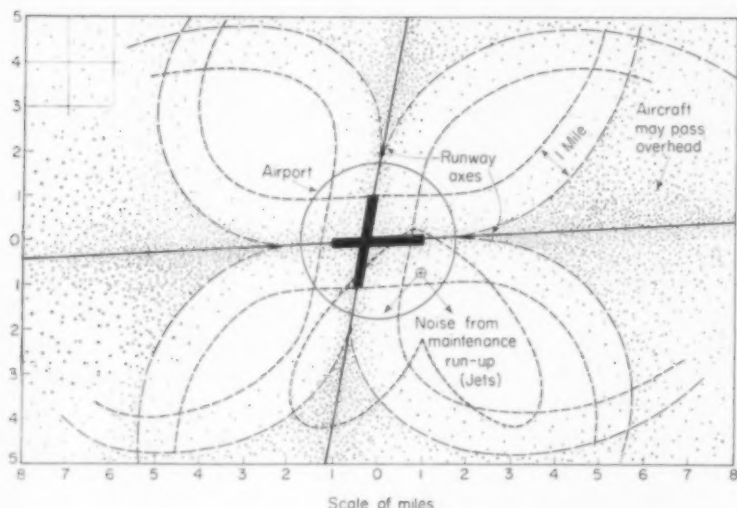
FIG. 4. Hypothetical layout showing noise pattern around an airport.

diagram plan of an airport with typical flight patterns. It is usual for landing aircraft to align themselves with the runway at least five or six miles away at a height of about 1500 ft and then to descend at reduced engine power (sometimes with bursts of full power) at a gradient of about 1 in 20–30 (i.e. about 2–3° until they touch down on the runway. Thus they keep to a narrow course and the noise is mainly restricted to this lane; but it is then that the characteristic whine of jet aircraft, due to the air compressors, is most noticeable, because the aircraft is low and therefore close and high frequencies are relatively unattenuated and unmasked by low-frequency noise. This whine can be quite annoying and the extended low flight of landing aircraft causes many complaints of their loudness.

The noise pattern of aircraft taking off is rather different. Aircraft taxying to the start of the runway are not very noisy. When in position for the take-off a pre-flight check of the controls is made with the engine running at full power for about half a minute, and the run is then commenced. The engine remains at full power for the first 2–3 miles from the start of the take-off run, by which time the aircraft will have gained 500 ft or so in height. The engine is then throttled back to climbing power and, unless already on it, the aircraft may begin to turn on to its outbound course. Normally by this time the aircraft is beyond the perimeter of the airport

and the fanning out for different routes spreads the noise of all the flights over quite a large area. This may or may not be an advantage; more land is affected but the frequency of occurrence of the loudest noises is reduced at any one point.

The question whether jet or propeller aircraft cause the greater noise nuisance is sometimes argued. Most people assume that jets are worse because they make more noise; but the distance from the noise source is also important and it is claimed for some jets that they have a steeper angle of climb (about 5° as against about 3° and that the extra height gained at any particular distance compensates for the louder noise source. Extra height would obviously give some relief from noise along the flight path, but this effect is reduced as one gets off the line of flight; and there is evidence that the greater heights actually obtained in practice by jets compared with propeller aircraft are insufficient to offset the higher noise levels produced by the jets.

Maintenance running

In addition to aircraft flights there is another source of noise at airports, namely, the running-up of aircraft engines for maintenance purposes. As the aircraft is stationary the noise contours will be similar to those of pre-flight running up (see Fig. 1), but the noise nuisance to surrounding buildings may be greater because the maintenance area is often nearer than the start of the runway to the boundary of the airport, and also the running-up periods will normally be much longer at all engine revs (including full power) than for pre-flight checks. Moreover, although flying activity is greatly reduced at night, maintenance running is not, and noise at night is a far worse nuisance than noise by day because it interferes with sleep. On the other hand it is possible to use noise mufflers for ground maintenance running of jet engines, which are the greatest noise producers, and this should reduce the noise by some 20 dB. These ground mufflers are already in common use, but they entail setting up the aircraft (or the muffler if it is a mobile one) in the correct position and this may not be done for short periods of maintenance running unless there is strict supervision of the maintenance staff. Baffle walls or banks are sometimes used instead but they are less efficient and the noise reduction at particular spots is less predictable; they are however the only means of reducing the noise from piston-engine aircraft.

HELIPORTS

A separate problem of particular importance in regard to noise is that of heliports. Heliports are associated with city centres and the noise problem therefore concerns public buildings and offices more than dwellings, although many dwellings will undoubtedly be affected to some extent. Points of importance in regard to heliports are:

(a) For economic reasons large helicopters will be used—much larger (and noisier) than the tiny machines so far used in trial services over London.

(b) Contrary to popular belief normal helicopters do not take-off vertically. The angle of ascent under favourable weather conditions is rarely more than 30° to the horizontal, and often it is very much less because a low angle of climb is preferred.

(c) For various reasons jet helicopters (such as the Rotodyne) will inevitably

be used for inter-city helicopter service. These rotor-tip jets produce a very high noise level.

(d) Vertical ascent by Rotodynes will be to a limited height only, probably 200 ft at the most, when normal take-off flight (rising at 30° or less) will commence. Moreover a ceiling height of 1000 ft (or 1500 ft at the most) may well be employed for inter-city helicopter flights, to avoid other aircraft. Therefore, although the area exposed to the greatest noise will be minimized by the vertical take-off, the noise fall-off along the flight path will be gradual and the whole flight path will experience considerable noise nuisance.

Even with vertical take-off up to 200 ft the noise nuisance from heliports may be more severe in some respects than around airports, because of the greater concentration of buildings in cities. In a published paper on heliport noise (PARKIN, 1959) it is estimated that the distances at which large jet helicopters will produce noise levels that are the highest that can possibly be tolerated in offices, in which telephoning can only be done with difficulty, are at least 6000 ft if the office windows are open, 1700 ft with single windows closed, and 250 ft with efficient double windows. The propagation of noise over the roofs of cities is little different from the spread over less built-up areas (PARKIN and SCHOLES, 1958), although local screening near the ground will of course be much more prevalent. The weakness of the roofs of some buildings (such as theatres) will be more apparent in cities because the roofs are proportionally more exposed, the walls being partially screened; but the means of protecting the buildings will follow the same principles.

PROTECTION OF BUILDINGS

The present position in regard to aircraft development and the policy controlling it holds out little hope of any reduction of the total noise, which in fact is much more likely to increase—unless vertical take-off to high altitudes can be developed sufficiently to be brought into general use. At best this is a long-term prospect. The present problem is seen to be a very extensive one geographically, and within the area exposed to noise around an airport (say 10–15 miles radius) there may be many thousands of buildings that are sensitive to noise, including dwellings, schools, libraries, hospitals and offices. How can these buildings be protected? It is proposed first to consider the general problem of the sound insulation of buildings against external noise, and then the practical application to different building types.

Principles of noise protection

To protect against noise the first requirement is a barrier of sufficient weight. The heavier a wall, roof or floor, the better will be its sound insulation. Fig. 5 shows how weight and sound insulation are related, about 5 dB insulation being added for each doubling of the weight. But in addition it is important that the insulation barrier should be complete and as uniform as possible, with no air-gaps and no areas of weak insulation. The majority of existing buildings have fairly heavy outer walls (9 in. solid or 11 in. cavity brick, or concrete of equal weight) capable of giving about 50 dB sound reduction. Roofs will usually be less but (apart from factory roofs of single sheeting) will probably have 35–45 dB insulation. But if there are ordinary windows these will have only 17–20 dB basic insulation when closed, the insulation of any open portions being of course nil. Assuming that the windows

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amount to 25–50 per cent of the wall area the net insulation of a building of this
construction will be 20–25 dB when the windows are closed and only 5–10 dB
when the windows are open. It is therefore apparent that in any building that is
dependent on open windows for ventilation there must be many occasions when
the noise reduction is no more than 5–10 dB, which is very little protection indeed.
Thus we are faced at once with a critical issue, namely that if we want any reason-
able increase of sound insulation in any ordinary building (other than by the
temporary expedient of closing the windows) we must go right over to artificial
ventilation, in order that the windows may be kept closed. There are other pre-
cautions we must take as well, but they will only avail us if we have artificial ventila-
tion. And satisfactory artificial ventilation for summer conditions usually means
full air-conditioning.
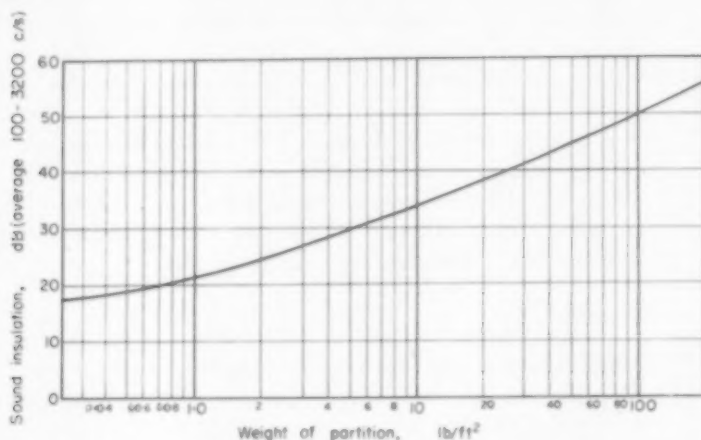
Fig. 5. Sound insulation of solid walls according to their weight.

Windows

When ventilation is provided by other means the windows can be sealed. Single
windows will then give about 25–30 dB insulation depending on the weight of the
glass. The insulation can be improved by providing double windows, which are
capable of giving 40 dB insulation, or perhaps a little more if thick glass is used.
But double windows for sound insulation require separate frames if possible, and
in any case quite a wide air space between the glass—preferably not less than 6 in.
whilst 8–12 in. is better. To be fully effective the glazing should be permanently
sealed on one side, the other side being openable only for cleaning purposes; if the
whole window is openable insulation will be lost even when the window is closed.
Lining the reveals of a double window with sound absorbent improves the insula-
tion. The basic sound reduction values of various types of window are given in
Table 1.

The approximate net values of sound insulation (averaged for the frequency
range 100–3200 cycles per second) against external noise obtainable in buildings of
various types of constructions etc. are summarized in Table 2.

TABLE 1. SINGLE AND DOUBLE WINDOWS

Construction	Approximate sound insulation in dB (average 100–3200 c/s)
Wide-open window	About 5 dB
Slightly open single window	10–15 dB
Closed "openable" single window	17–20 dB
Sealed single window (24–32 oz glass)	23–25 dB
Sealed single window ($\frac{1}{4}$ in. plate glass)	27 dB
Sealed single window ($\frac{3}{8}$ in. plate glass)	30 dB
Closed "openable" double window (any weight of glass, 8 in. airspace, absorbent reveals)	30–33 dB
Sealed double window (32 oz glass, 8 in. airspace, absorbent reveals)	40 dB
Sealed double window ($\frac{1}{4}$ in. plate glass, 8 in. airspace, absorbent reveals)	42 dB

TABLE 2. INSULATION AGAINST EXTERNAL NOISE

	Construction		Windows (25–50% area of wall)	Means of ventilation	Approx. net sound insulation (average 100–3200 c/s)
	Outer walls	Roof			
(a)	Any type	Any type	Single or double (openable)	Natural (Windows open)	5–10 dB
(b)	Heavy curtain wall, or brick or concrete (35–50 dB)	Pitched roof of tiles or sheeting with flat ceiling under, or concrete flat roof (35–45 dB)	Single (openable)	Natural (windows closed)	20–25 dB
(c)	As above	As above	Double (openable)	Natural (windows closed)	30–35 dB
(d)	Heavy brick or concrete e.g. 9 in. brick (50 dB)	Concrete flat roof (45 dB)	Double (sealed—32 oz glass with 6–8 in. airspace)	Artificial (absorbent lined ducts)	40–45 dB
(e)	As above	As above	Double (sealed—$\frac{1}{4}$ in. or thicker plate glass and 12 in. airspace)	Artificial (ducts adequately lined with absorbent)	45–50 dB
(f)	9–18 in. brick, or concrete of equal weight (50–55 dB)	6–12 in. concrete with suspended ceiling (50–55 dB)	None	As above	50–55 dB

From the last column in this table it can be seen that the net insulation values obtainable in the external structure of buildings apparently offer roughly equal steps (of about 10 dB) in noise reduction over the available range. But (b) and (c) are of course only made operative by closing the windows and forgoing ventilation. If the noise is likely to be continuous or frequently recurring and protection may be required most of the time, these items do not in fact provide satisfactory solutions. Items (d) and (e) on the other hand are permanent solutions offering adequate protection for most buildings affected by airport noise, but they are of course very costly. They may not be adequate for very severe noise exposure or for specially sensitive buildings such as concert halls; "double envelope" construction will probably be necessary in such cases.

It should, of course, be appreciated that when a building is artificially ventilated the air still has to be brought in through an opening, and precautions must be taken not to let in the noise as well. This is not so difficult a problem, for the following reasons:

(a) The size of the air inlet is relatively small compared with the total area of open window required for natural ventilation, because the air is forced in by fan.

(b) The opening can be placed in a position that is least exposed to noise.

(c) The air can be fed into the building along a duct of adequate length suitably lined with acoustical treatment to give the necessary attenuation of the noise. Reductions of 1–3 dB per foot run of duct are usually obtained, with 2–3 dB extra for each bend.

Dwellings

It has already been shown that any significant increase in the structural sound insulation of a building must be accompanied by artificial ventilation. It follows that the structural protection of dwellings (especially existing dwellings) from aircraft noise is virtually impracticable. The artificial ventilation of dwellings simply cannot be contemplated. The only real solution for new dwellings is to keep them away from the noise. A limited benefit may perhaps be obtained by planning them with, as it were, their "backs" to the noise. And, of course, individual rooms can have openable double windows to give optional protection for short periods, or particular rooms might even have sealed double windows with fan-assisted natural ventilation from other parts of the house.

Although it has been implied that the structural insulation of dwellings cannot normally be improved, it does not follow that the structural insulation of new dwellings may be entirely disregarded. For example, unnecessarily large windows and very lightweight roof constructions should be avoided, otherwise the poor insulation will be even worse. And in the case of existing dwellings a few palliatives may be possible for particular houses with local problems or with special weaknesses, e.g. some roofs with very poor insulation might be improved by sealing or by extra weight.

Offices, etc.

The general position in regard to dwellings applies also to other types of building (e.g. most schools and hospitals) where for one reason or another it is not practical to provide artificial ventilation in the majority of the rooms. In some cases certain

rooms only might be given special protection, with artificial ventilation. But large office blocks are a class of building in which the provision of artificial ventilation throughout may not be regarded as unwarranted if noise exclusion justifies it. In fact, such ventilation is sometimes provided without any regard to noise reduction requirements but simply because it simplifies planning and, if supplementary artificial lighting is also accepted, permits much deeper office space. But mechanical ventilation has a wide range of performance, and full air-conditioning (which includes humidity control and adequate cooling facilities) is not often used in offices in this country, reliance being placed on opening windows to augment the mechanical ventilation during the short spells of really hot weather normally experienced. This arrangement is unsatisfactory for noise control because not only is the sound insulation lost whilst the windows are open, but also the mere fact that the windows are openable usually reduces their efficiency when closed by some 7–10 dB. This is due to the gaps which normally occur at the closing edges of regularly opened windows.

NOISE CONTROL STANDARDS OR CRITERIA

Standards of noise protection may take several different forms. Some classes of building, such as concert halls, require full protection against external noise if they are to function properly. A fairly precise spectrum can be given of the maximum permissible noise levels at all frequencies inside the room, and the designer must anticipate the maximum noise exposure of the building and provide in the construction for the necessary noise reduction. The difficulty lies chiefly in assessing the worst noise likely to reach the building. If the noise is steady and fairly continuous, such as heavy road traffic or machinery noise from a nearby factory, it can be measured. But aircraft noise is more difficult to assess because of its intermittency and the many other variables listed above; and even if the present noise exposure is established there is the possibility of the noise increasing in the future due to the development of more powerful aircraft, or perhaps due simply to a local change in flight paths. Thus a policy decision on the noise level to be worked to has to be made.

The following criteria (Table 3) for four different classes of auditoria in which acoustic conditions are important have been suggested (PARKIN and HUMPHREYS, 1958).

TABLE 3

Octave band of noise (c/s)	Criteria of maximum permissible noise levels (dB) in auditoria:			
	a	b	c	d
37–75	53	54	57	60
75–150	38	43	47	51
150–300	28	35	39	43
300–600	18	28	32	37
600–1200	12	23	28	32
1200–2400	11	20	25	30
2400–4800	10	17	22	28
4800–9600	22	22	22	27

The four criteria apply as follows:

a	..	..	Concert halls (complete quiet)
b	..	..	Concert halls (reasonably satisfactory)
			Opera houses
			Theatres (over 500 seats)
			Broadcasting studios
c	..	..	Theatres (up to 500 seats)
			School assembly halls, classrooms and music rooms
			General purpose halls
			Large conference rooms
d	..	..	Small conference rooms (up to 20 persons)
			Cinemas
			Churches
			Courtrooms

There is another class of buildings, such as offices or workrooms, in which the acoustic climate is not so exacting, usually because the occupants themselves un-avoidably make some noise. But communication is important and criteria in such cases are based mainly on the ability to understand speech, either direct or on the telephone. For this purpose a unit called the Speech Interference Level (abbreviated SIL) can be used, provided the low-frequency components of the noise are not excessive. The SIL is obtained by averaging the octave-band noise levels in the three octaves 600–1200 c/s, 1200–2400 c/s and 2400–4800 c/s. Suggested noise ratings, due to various SIL's of intruding or background noise, of two kinds of offices (private and large clerical or typing offices), and of telephone use in any office, are given in Fig. 6.

These criteria relate to conditions inside a building and they assume that some control of noise transmission into the building is possible, either in the planning or in the structural design of the building. In dwellings generally such control is not possible (the only form of control being suppression or reduction at the source) and criteria must be applied to the residential neighbourhood rather than to the buildings themselves. Environmental noise levels have to be related to degrees of disturbance of the community.

No neighbourhood noise level criteria have been established in this country up to the present time, but the Americans have produced tentative criteria. These criteria were based originally on reaction to industrial noise (STEVENS et al., 1955), their purpose being to determine the effect on a community of introducing an un-accustomed noise, say a new factory or a noisy machine. The criteria have now been extended to assessing the nuisance of aircraft noise to residential areas around air-fields (PIETRASANTA and STEVENS, 1958). The technical basis of a criterion of this sort is a noise level rating obtained from a measured or calculated noise spectrum in the neighbourhood, to which corrections are applied for various conditions such as the level of the normal background noise, the nature, time and frequency of occurrence of the new noise, and the previous exposure of the residents to similar noise. The composite noise rating is then related on a chart to various reactions by the community as a whole. The Americans have also suggested a method of com-piling a set of effective noise rating contours for airfields derived from the same

items of information, the use of which should help to crystallize the noise problem for a particular airport. Fig. 7 shows the form these contours can be expected to take for aircraft taking off.
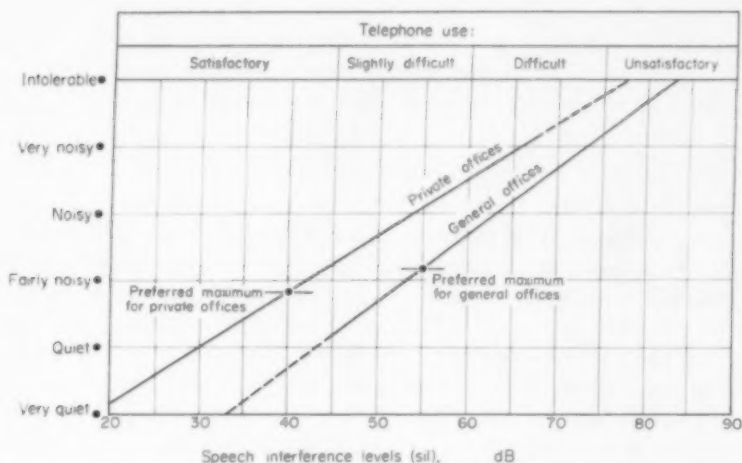
FIG. 6. Criteria of noise nuisance in offices based on Speech Interference Levels.
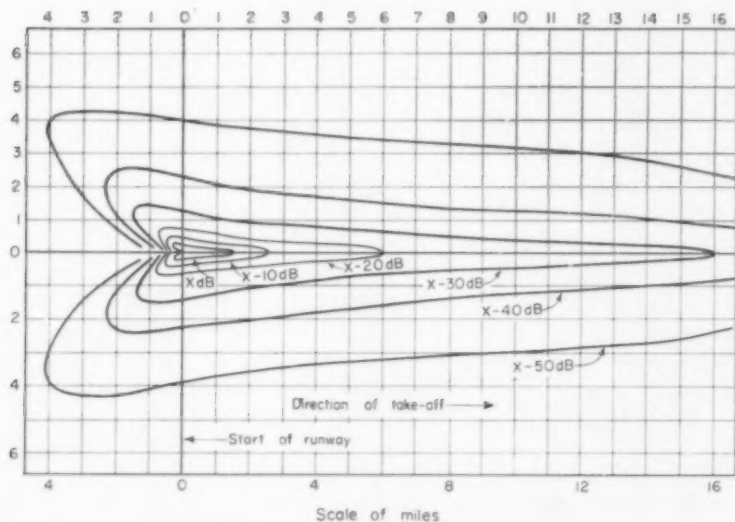
FIG. 7. Noise contours of jet aircraft taking off.

Establishing any criteria for assessing people's reactions to aircraft or other outdoor noise is a very complicated task involving extensive social survey work coupled with a great many measurements of noise level. Aircraft in particular are a very variable noise source, and people's response to a factor that affects their comfort, their efficiency, their sleep, their enjoyment and their physical well-being

can naturally be expected to vary widely. Moreover, subjective reactions are diffi-
cult to collect as well as to evaluate. A scale of nuisance due to aircraft noise is
not likely to benefit the subjects of a social survey from whom the necessary informa-
tion for compiling it is obtained. The two main reasons for establishing such a scale
are (a) to enable decisions to be made whether or not to bring people into a noise-
affected area, by building houses or offices there, and (b) to enable a particular com-
plaint about noise to be judged (perhaps for legal purposes) in relation to the
average reaction of members of a community to similar noise.

CONCLUSION

To sum up generally it can be said that there is no hope of reducing the noise
at airports or within a large area around them, unless aircraft with vertical take-off
operating to a reasonably high altitude can be developed, which would limit the
area subjected to the loudest noise, though it would increase the noise exposure of
that area. Normally, noise is a by-product of power, and reducing the power of air-
craft is not likely to be acceptable. This is not surprising when one considers how
dependent upon power is our present standard of living, which few people would
agree to lower. If then the noise source cannot be abated in any way, the alternative
is to insulate the buildings within the noisy zones. This is feasible for some buildings,
though moderately expensive. But for housing it is not feasible, which can only
mean "sterilizing" large areas of land around airports so far as new housing is
concerned. Prohibiting housing also precludes other types of building which cannot
be situated too far away from dwellings, and the general value of the land is therefore
reduced.

Thus we are faced with a noise source with no apparent prospect of abatement,
but rather of increase, and habitations (the most important of all buildings) with no
possibility of improved noise protection. Put like that it is a problem (like the road
traffic problem) with no foreseeable answer. But although protecting dwellings
from noise may be a practical impossibility, reducing the source of noise (i.e.
civilian aircraft noise) is not necessarily so, even though there may be resistance
from some quarters. Some people, it is argued, like noise when (like aircraft noise)
it is symbolic of progress in a particular sphere, but it is hardly social justice to
sacrifice the rest of the community to so small a section of it. If then noise relief is
wanted in dwellings and in other buildings vulnerable to noise, and if it is also
wished to preserve reasonable amenities in large areas out-of-doors, the only course
open at present is to press for noise reduction at the source.

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DUST EXPOSURES IN EGYPTIAN FOUNDRIES

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Abstract—A cross-section of Foundry Industry of Egypt was surveyed with the aim of evaluating the level of dust exposures. Dust count concentrations, size distribution analyses and determination of free silica content of dust was made.

The results showed that there are existing dust hazards in the Foundry Industry of the country.

Wetting of the material proved to be an efficient way of dust control.

THE FOUNDRY INDUSTRY

WHEN considering prevention studies of dust exposures, especially free silica containing dust, one cannot ignore foundries. Dust is produced in almost all the processes that take place in this industry. Much has been done about foundry dust control, and the only safe means of protecting its workers lies in complete mechanization and enclosure of the majority of the processes.

In Egypt, there is only one big completely mechanized foundry and very few partially mechanized; the majority are unsatisfactorily controlled with manual processes being carried out.

The first and only survey in Egypt of foundry dust exposures was conducted in the summer of 1958 (VALIC *et al.*, 1959). In this survey, a large size foundry employing 180 workers was studied. Because of an almost complete lack of dust control measures, a very inefficient system of housekeeping in that plant and very high production at the time of the survey, higher levels of dustiness than permissible were found in almost all the operations and processes. The mean dust concentrations ranged from 25 mppcf in machine moulding to 85 mppcf in sand blasting. The free silica content of the airborne dust by weight varied from 42 per cent in moulding to 75 per cent in sand blasting. The petrographic analysis, giving the free silica concentration by count in different particle size groups, showed that quartz was present in all size ranges in variable proportions which decreased with decreasing particle size. The favourable fact found was that the free silica content of the particles below $2 \cdot 5 \, \mu$ was considerably lower than that of larger particles and that the relatively high percentages of quartz were in the large size groups of non-hygienic importance above $5 \, \mu$.

Since these high figures for dust exposure were obtained, it was planned that a general environmental investigation should take place in order to get a fair idea of the average dust exposure in this industry. In the present study nine other foundries were selected to give a reasonable representation of the foundry industry in Egypt with respect to size and amount of production. Foundries employing less than ten workers were not included although these constitute a little more than 50 per cent of all the foundries in the country.

The main operations that take place in the foundry industry are the same everywhere and can be summarized in the following steps: Preparation of moulding materials; making of moulds and cores; melting and pouring of molten metal; removal of castings from moulds and removal of cores; cleaning of castings.

The following points should be mentioned about the plants surveyed:

(1) All foundry operations take place in one hall.

(2) Two out of the nine foundries studied, namely Nos. 1 and 6, are situated in nearly open air, i.e. the labourers work in a wide area which has no walls but only a roof to protect them from the sun and so they benefit from the prevailing wind.

(3) In all foundries, moulding is by hand in the ground.

(4) No means of control are taken except in foundries Nos. 3 and 9 where wetted sand and clay are used.

(5) Apart from foundries 1 and 6 where labourers work in three shifts, the work is performed in two shifts.

It should be pointed out that the study was conducted in summer under nearly the same meteorological conditions as the first study (VALIC et al., 1959).

METHODOLOGY

The standard technique employing standard midget impingers in connection with a hand operated sampling pump was used for collecting samples for dust counting and determination of particle size distribution. Samples were taken at the workers' breathing levels, as well as in the general room air, for periods of ten minutes. Samples containing visibly high dust concentrations were further diluted as required. A blank count determination was made for every 8 samples counted. All counts were made within twenty-four hours after collection. Counts were done in a Spencer cell under magnification of $100 \times$. Particle size distribution was made by a Porter graticule calibrated against a stage micrometer, using an oil immersion objective. An electrostatic precipitator (M.S.A.) was used for collecting samples for the estimation of free silica content which was determined both by chemical methods (TROSTEL and WYNNE, 1940) and by differential thermal analysis (GRIMSHAW and ROBERTS, 1953).

RESULTS

TABLE 1. PERCENTAGES BY WEIGHT OF QUARTZ IN THE AIRBORNE DUST AT VARIOUS LOCATIONS OR OPERATIONS

Foundry number	Operation or location			
	Cleaning or blasting	Screening	Rest of the operations and areas	Mean concentration in the foundry hall
1	38·4	—	12·5	25·4
2	57·3	32·5	22·1	37·3
3	40·0	—	12·6	26·3
4	64·5	25·9	24·1	38·2
5	45·3	25·2	21·9	30·8
6	72·2	25·7	28·8	42·2
7	32·4	29·6	14·1	25·4
8	58·7	—	25·6	42·2
9	44·5	27·8	26·3	32·9
Mean concentration for location or operation	50·4	27·8	20·9	—

As the results obtained for free quartz by the differential thermal analysis did not show a marked difference from those obtained by the chemical method (the maximum difference being ±5 per cent), only the results of chemical analysis are presented. Table 1 shows the percentages of free silica in the suspended dust in the areas of cleaning or blasting, screening, and in the rest of the area where other operations are carried out. In 44 per cent of the foundries the free silica content in cleaning or blasting exceeds 50 per cent, otherwise the percentages in all the other samples lie between 12·5 and 45·3 per cent.

TABLE 2. DUST COUNTS AT VARIOUS OPERATIONS OR LOCATIONS EXPRESSED IN MILLIONS OF DUST PARTICLES PER CUBIC FOOT OF AIR

Operation or Location	Number of samples	Concentration			Standard error of the mean
		Maximum	Minimum	Mean	
Screening dry material	16	642·0	143·3	278·9	40·26
Screening wetted material	16	17·8	2·0	7·0	1·00
Mixing and sand conditioning	33	57·3	10·3	23·5	2·48
Moulding and pouring	59	127·5	2·6	14·8	2·42
Break-out	39	49·0	8·3	18·8	1·17
Drying	7	12·2	4·2	7·5	0·93
Cleaning or blasting	38	325·0	17·2	44·2	4·51
Furnaces	33	62·5	1·9	13·2	1·96
Workshops	8	16·0	4·4	8·4	1·46

Dust levels at various operations are shown in Table 2 which gives the maximum, minimum and mean counts as well as the standard error of the mean for each operation. In only one operation, namely screening of dry material, did the average dust concentration exceed 50 mppcf, which is the recommended threshold limit value for a nuisance type of dust free from quartz or with a free silica content less than 5 per cent (THRESHOLD LIMIT VALUES FOR 1959). Apart from cleaning or blasting, the percentages of free quartz in the samples collected lie in the range between 5 and 50 per cent for which type of dust the MAC is 20 mppcf. The mean level of dustiness does not exceed this threshold limit except in screening of dry material

TABLE 3. DISTRIBUTION OF SAMPLES BY DUST COUNT GROUPS

Count in mppcf	Number of samples	Frequency (%)	Cumulative frequency (%)
< 10	67	26·91	26·91
10–25	112	44·98	71·89
25–50	44	17·67	89·56
50–100	7	2·81	92·37
100–200	9	3·61	95·98
>200	10	4·02	100·00

and in the mixing and sand conditioning areas. In the latter the limit is only exceeded by few mppcf. For cleaning or blasting operations and dust with more than 50 per cent free silica content, the dust concentrations should not exceed 5 mppcf.

The distribution of samples by dust count groups (Table 3) shows that over 75 per cent of the results are lower than 30 mppcf, the MAC for foundry dust in all operations except sand blasting suggested by HATCH *et al.* (1939). The other 25 per cent of the results with higher concentrations are mostly due to cleaning or blasting and the screening of dry material.
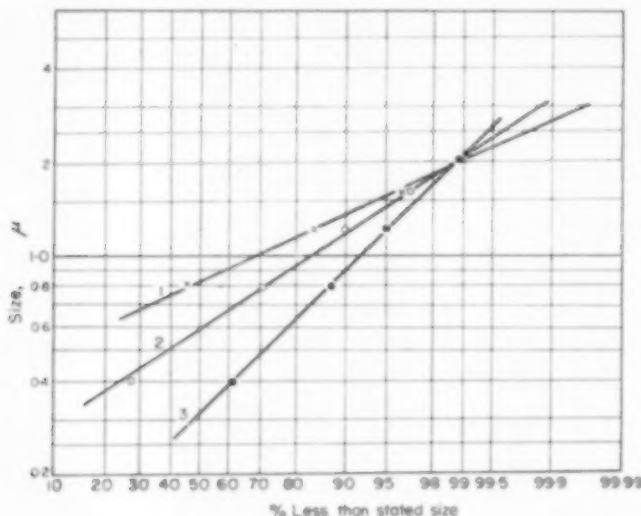
FIG. 1. Representative size distribution curves.

1. Cleaning or blasting	2. Screening dry material	3. Moulding and other jobs
$M_g = 0.83\mu$	$M_g = 0.58\mu$	$M_g = 0.31\mu$
$\sigma_g = 1.45$	$\sigma_g = 1.81$	$\sigma_g = 2.42$

As to particle size distribution, three representative size analyses are shown in Fig. 1, for cleaning or blasting, the screening of dry material and for moulding and other jobs in the different areas of the foundries; they are plotted on logarithmic-probability paper. Fig. 1 also shows the computed statistical parameters of the corresponding distributions, namely the geometric mean and the standard geometric deviation (DRINKER and HATCH, 1956). It is clear from the curves that nearly all the dust particles were of the respirable size below 5μ and that practically 99 per cent of the particles were below 2μ. Seventy per cent of the particles collected during cleaning or blasting operations were below 1μ. The corresponding percentage for screening of dry material was 84 per cent and for other jobs about 92 per cent. The respective geometric mean sizes for these operations were 0.83, 0.58 and 0.31 μ.

DISCUSSION

In spite of the fact that the foundries visited were old and modern methods were lacking, the mean levels of dustiness were definitely much lower than those reported in an earlier investigation (VALIC *et al.*, 1959), except for screening of dry material

TABLE 4. MAXIMUM, MINIMUM, AND MEAN DUST CONCENTRATIONS FOR EVERY OPERATION OR LOCALITY AS WELL AS THE ABSOLUTE VALUES IN THE GENERAL ROOM AIR IN EACH FOUNDRY (MILLIONS OF PARTICLES PER CUBIC FOOT)

Foundry number		Operation or locality									Absolute values
		Screening		Mixing and sand conditioning	Moulding and pouring	Break out	Drying	Cleaning or blasting	Furnaces	Workshops	
		Dry materials	Wetted materials								
1	No. of samp.				6	4		7	2		19
	Max.				9·0	30·0		42·7	3·7		42·7
	Min.				3·0	16·3		17·6	3·2		3·0
	Mean				5·6	22·0		25·6	3·4		16·2
2	No. of samp.	4		4	9	5	2	4	2		30
	Max.	642·0		22·1	127·5	27·6	7·0	325·0	62·5		642·0
	Min.	428·4		16·7	4·1	16·5	6·1	41·0	15·8		4·1
	Mean	529·4		19·6	33·2	21·6	6·6	159·7	39·2		111·1
3	No. of samp.		5		7	6		3	5		26
	Max.		8·2		25·6	17·8		28·5	14·7		28·5
	Min.		2·6		12·4	11·3		24·9	4·3		2·6
	Mean		5·7		16·6	14·7		26·3	10·7		14·0
4	No. of samp.			5	3	3		6	6		23
	Max.			24·3	18·0	18·5		34·6	22·6		34·6
	Min.			16·1	11·4	12·5		22·4	8·1		8·1
	Mean			20·5	14·6	16·0		28·2	14·8		19·7
5	No. of samp.	3		10	2	5	3	4	2	2	31
	Max.	324·8		57·3	18·6	23·2	12·2	63·7	14·1	9·4	324·8
	Min.	155·7		18·6	15·5	12·4	4·2	25·8	13·0	6·2	4·2
	Mean	233·1		31·7	17·0	17·3	8·0	41·5	13·6	7·8	44·1
6	No. of samp.	3		10	3	6		3	2		27
	Max.	240·9		43·8	12·9	17·2		69·2	13·7		240·9
	Min.	162·0		10·3	7·6	8·3		17·2	11·6		7·6
	Mean	199·0		24·0	10·0	13·2		35·7	12·6		40·0
7	No. of samp.	4	(5)		7	3	2	3	5	3	32
	Max.	187·8	(17·8)		30·3	25·6	8·8	62·1	36·0	16·0	187·8 (62·1)
	Min.	145·2	(3·5)		2·6	14·2	6·6	27·4	3·7	5·3	2·6
	Mean	167·2	(9·6)		11·4	19·3	7·7	41·1	17·2	11·4	39·4 (15·9)
8	No. of samp.	2	(3)	4	6	4		3	4		26
	Max.	236·1	(10·1)	32·4	23·0	49·0		46·0	9·4		236·1 (49·0)
	Min.	143·3	(4·2)	12·8	3·4	18·1		30·1	1·9		1·9
	Mean	189·7	(7·7)	21·7	11·3	31·5		35·6	5·4		34·3 (18·0)
9	No. of samp.		3		16	3		5	5	3	35
	Max.		6·2		35·6	20·2		30·3	13·8	8·3	35·6
	Min.		2·0		3·8	13·5		14·6	6·1	4·4	2·0
	Mean		3·9		10·5	16·6		22·1	9·6	5·7	11·6

where the mean dust count was 279 mppcf. From the percentages of the frequency distribution of samples by dust count groups (Table 3), we see that less than 25 per cent of the results were above 30 mppcf.

Since, as was mentioned before, all the operations in each foundry are carried out in one hall, it is preferable to study the degree of dustiness in each foundry separately. Table 4 gives the maximum, minimum and mean dust concentrations for every operation or locality in each foundry. It also shows the absolute maximum, absolute minimum and mean concentrations in the general room air. Taking into consideration that the mean free silica content in the general room air for each foundry lies between 5 and 50 per cent (as can be seen from the last column of Table 1), we find the average dustiness of five foundries out of the nine studied exceeded the threshold MAC. These were the foundries using dry material when screening.

The striking feature observed, is the effect of moisture on the amount of dust produced in screening operations. When the material is wetted, the mean concentration (Table 2) is 2·5 per cent of the corresponding concentration when the screened material is dry. In foundries 7 and 8, experiments were carried out on the effect of wetting on dustiness. When the material was wetted before screening, the mean degree of dustiness was reduced to 5·7 and 4·1 per cent respectively and the mean dust concentration in the general room air of these foundries was reduced from 30 mppcf to 16 mppcf in foundry 7 and from 34 mppcf to 18 mppcf in foundry 8. Thus the level of dustiness became less than the MAC. This shows clearly the great deal that water can do in reducing the degree of dustiness. This cheap method of control is also very effective in mixing, sand conditioning and breaking out operations. It prevents building up of high dust concentrations.

CONCLUSIONS

In conclusion one can say that dust concentrations in Egyptian foundries are not satisfactory. A detailed programme for the control of airborne dust in foundry environments was suggested in another paper (VALIC et al., 1959a). The essential recommendations can be summarized as follows:

(1) Water should be utilized in almost all the processes that take place in this industry, with special reference to screening, mixing, sand conditioning and breaking out operations.

(2) Cleaning or blasting operations should be isolated from the other processes and proper control and protection of the workers involved should be instituted. Sand in blasting should be replaced by metal shot or by any other material free of quartz.

(3) Natural ventilation should be made use of in closed foundries.

(4) Proper housekeeping should be maintained. Accumulation of dust on overhead beams and rafters as well as on materials stored in the foundries should be prohibited in order to prevent redispersion of such accumulations by vibration and draughts.

(5) High silica parting compounds used by foundries should be replaced by harmless materials.

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LE CONTRÔLE CHIMIQUE DES DOSES NOCIVES
DE L'AIR SUR LES LIEUX DE TRAVAIL

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L'une des tâches fondamentales de l'hygiène du travail consiste dans les soins que l'on consacre à la pureté de l'atmosphère des ateliers. Si l'on travaille dans un milieu renfermant certaines substances biologiques actives (poison ou produit nocif de l'industrie), on dit que l'on a été exposé à cette substance.

Si nous désirons *caractériser* cette *exposition*, il convient donc:

(a) de connaître la *caractéristique hygiénique fondamentale* de la substance en question, c'est à dire de connaître ses propriétés physiques, chimiques et généralement toxiques;

(b) de connaître la *caractéristique hygiénique du milieu de travail*, c'est à dire de connaître le degré de concentration de cette substance dans l'atmosphère des ateliers, les changements de concentration dans le milieu de travail notamment en rapport avec la durée de travail et avec l'organisation du travail;

(c) de connaître la *caractéristique hygiénique de la production analysée* en général, soit de connaître les circonstances qui causent la contamination du milieu de travail, cette dernière pouvant être déterminée par la technologie ou le procédé de production et son organisation ainsi que par le mode de travail et les opérations du travailleur lui-même. La caractéristique hygiénique de la production étudiée dépend étroitement de celle du milieu de travail en vertu de quoi il convient d'analyser ces deux facteurs en corrélation.

(d) de connaître l'ensemble des facteurs qui *caractérisent le passage de ladite substance du milieu extérieur*, entourant l'organisme, *au milieu intérieur de l'organisme;* il existe une grande différence entre la pénétration par les voies respiratoires (il s'agit là d'une entrée directe de la substance dans le sang) et la pénétration par voie digestive où peuvent survenir à des modifications de la substance soit dans le milieu acide gastrique ou le milieu alcalin intestinal.

Pour apprécier l'absorption il faut également tenir compte de la possibilité d'une répartition inégale de la substance dans le contenu stomacal ou intestinal, de l'adsorption de la substance aux aliments, des facultés émulsives de la bile, etc. La voie d'absorption dans ce cas n'est pas directe, mais elle passe par le foie.

La caractéristique hygiénique fondamentale de la substance indiquera la manière d'agir de cette dernière dans l'organisme; de même on pourra déterminer son influence sur l'état de santé du travailleur: il s'agit d'un ensemble de réactions qui se dérouleront après pénétration de la substance dans le milieu intérieur de l'organisme. Ces réactions seront d'ordre primaire c'est à dire provoquées directement par la présence de la substance ou secondaire, provoquées par les réactions primaires en conséquence des réactions indirectes.

La caractéristique hygiénique d'une certaine substance est donc décisive pour l'appréciation de l'ampleur de son influence sur l'organisme de même que les autres circonstances importantes qui en dépendent tel le métabolisme éventuel de la substance, ce qui est nécessaire à ce métabolisme, comment cela surcharge l'organisme, etc. Tout cela créé en fait la *caractéristique des effets de la substance sur l'organisme:* l'action de la substance est répresenté par un ensemble d'indices différents et d'importance differente (les symptomes de l'action). S'il s'agit d'une action caractérisée par le changement d'une certaine fonction ou par de faibles changements de la structure qui très souvent disparaissent, il s'agit alors d'un effet réversible. Or, s'il se produit une réaction qui apparait sous la forme de trans-formations plus profondes de la structure terminées par la perte du parenchyme spécifique suivi des processus réparateurs s'effectuant difficilement, il s'agit alors d'une réaction irréparable comme celle provoquée soit par les substances très actives au point de vue biologique, soit par des substances qui, bien que moins dangereuses, ont agi pendant une période plus longue.

Comme il a été déjà dit, on peut apprécier les réactions d'une certaine substance selon divers indices importants (symptômes de réaction) comme ils sont donnés par la caractéristique hygiénique fondamentale de la substance. Par exemple: chez les substances irritables le facteur hygiénique d'efficacité est donné par la manifestation de l'irritation locale: il s'agit "d'un signe avertisseur" qui se produit habituellement avant la réaction de plus grande importance qui atteint tout l'organisme.

Le "signe avertisseur" analogue pourrait être également reconnu dans certaines modifications fonctionnelles du système nerveux central qui peuvent être constatées par exp. par les réflexes conditionnés ou par des modifications de l'EEG, par la méthode qui sert à mesurer les changements dans l'activité des réflexes cérébraux voire même par la méthode complexe psychologique. Toutefois faudrait-il encore décider dans ce cas du degré de changement admissible afin qu'il ne se produise pas un endommagement de l'organisme ou une cumulation des réactions.

La quantité de substance qui *pénétre dans l'organisme* dans les conditions du travail dans le milieu des ateliers dépend:

(a) des voies par lesquelles la substance pénètre dans l'organisme; les voies de pénétration différent d'après la facilité d'accès de la substance dans l'organisme de quoi dépend également la rapidité de pénétration de la substance dans le corps;

(b) de la manière avec laquelle le travailleur entre en contact avec la sub-stance pendant les conditions du travail;

(c) de la durée de ce contact, ce qui est habituellement donné par la tech-nologie de la production, par l'equipement en machines et en appareillages de la production et par les opérations de travail exigées par la technologie de production, par les installations mécaniques et enfin par l'organisation du travail;

(d) des propriétés physiques et chimiques de la substance, de son état, de sa tension de vapeur, de sa volatilité, etc. dans les conditions du travail.

Tout ce qui a été indiqué plus haut peut être résumé et complété comme suit: les substances chimiques utilisées dans l'industrie peuvent être divisées en deux groupes d'après les effets suivants:

I

(a) *La nocivité potentielle* qui dèpende de la substance elle-même, par ses propriétés physiques, chimiques et généralement toxiques.

(b) *La nocivité réelle* qui dans les conditions du travail doit être determinées dans chaque cas puis qu'elle résulte de la caractéristique hygiénique du milieu de travail et de la production considérée en général. Très souvent, la nocivité réelle est déterminée;

　　(i) d'après la technologie de la production utilisée,

　　(ii) d'après les types de machines et installations mécaniques,

　　(iii) d'après les conditions microclimatiques lors qu'elles ont de l'influence par exemple sur l'échappement des substances nocives dans l'espace libre de l'atelier ou sur la tension de vapeur de la substance dans l'atmosphère,

　　(iv) d'après le type de bâtiment et les possibilités d'aération naturelle du milieu de travail,

　　(v) d'après la manière avec laquelle travaille le travailleur,

　　(vi) d'après l'organisation due travail (rythmes, pauses, durée de la journée de travail, repas pendant le travail, etc.),

　　(vii) d'après la prédominance et l'importance d'une des voies d'accès de la substance dans le corps dans les conditions de travail.

L'analyse des échantillons d'air prélevés dans l'atmosphère de travail est la méthode relativement la plus rapide et la plus facile pour déterminer à chaque moment la qualité hygiénique du milieu de travail. Mais il convient de souligner ici qu'il est important de prendre correctement les échantillons de l'air destinés aux analyses afin de pouvoir utiliser les résultats analytiques pour l'évaluation hygiénique. Il faudra:

(a) choisir avec soin le lieu de prise des échantillons d'air tout en tenant compte de la technologie du procédé de production, de l'équippement mécanique, d'après le type de bâtiment et selon les courants d'air existants dans l'espace de production. Il faudra également analyser l'organisation du travail et les opérations des travailleurs, leurs deplacement dans l'atelier comme l'exige le procédé de production. Si l'on veut déterminer le degré de nocivité qui menace l'employé, il faut prélever les échantillons dans l'espace où respire le travailleur. Pour compléter, on recommande d'analyser aussi l'air dans l'atmosphère générale de l'atelier;

(b) choisir convenablement la durée de prise de l'échantillon d'air. La période pendant laquelle se fait ce prélévement doit englober le cycle entier du processus de travail; on devra tenir compte en même temps des opérations de travail et les échantillons devront être choisis précisément au moment où l'employé éxécute un travail dangereux.

Pour contrôler du point de vue hygiénique la pureté de l'atmosphère, on a élaboré des doses limites des substances nocives dans l'atmosphère des ateliers. Il s'agit ici d'un standard hygiénique qui doit servir:

(a) au contrôle des conditions hygiéniques dans le milieu du travail, à l'évaluation de l'efficacité hygiénique des installations techniques servant à assurer la propreté de l'atmosphère et etc.,

(b) aux projets des installations de production, des procédés téchnologiques et installations mécaniques voire même aux calculs des échanges d'air exigés des installations de ventilation dans les ateliers où se dégagent les vapeurs, poussières ou gaz nocifs.

Comme les autres régulateurs hygiéniques, les doses limites des substances nocives dans l'atmosphère sont également calculées pour un individu de santé et de résistance moyennes; il en résulte que même en tenant compte de ce regulateur on ne peut pas assurer en toutes circonstances qu'aucun individu ne sera pas atteint de maladie s'il effectue un long travail dans le milieu contenant la-dite substance nocive. On ne tient pas compte en effet des personnes fragiles ou allergiques à telle ou telle substance; en conséquence, il est nécessaire de faire un examen médical convenable des employés demandant un emploi et important d'effectuer des examens périodiques réguliers des personnes travaillant dans le milieu nocif.

On peut dire généralement que les doses limites des substances nocives dans l'atmosphère des ateliers sont basées sur des criteriums suivants:

(a) les effets de ces concentrations ne doivent pas provoquer des perturbations dans les organes (troubles cellulaires) ou encore des changement fonctionnels dans l'organisme qui se manifesteraient comme maladie; il ne doit pas se produire de réduction fonctionnelle qui modifierait la capacité de travail. Si l'on parle d'organe, il ne s'agit pas ici seulement d'organes parenchymateux du corps mais aussi du système nerveux central et périférique. Les changements sont détectés soit par les méthodes cliniques intégrales soit par des méthodes qui permettent d'enregistrer les deficiences fonctionnelles des organes;

(b) il ne doit pas advenir de changements fonctionnels même réversibles qui ne seraient pas suffisamment réparés en dehors de la journée de travail.

Les changements fonctionnels ne doivent pas dépasser un certain niveau, celui qui ne suffirait pas pendant la période de repos à ramener les changements fonctionnels du travailleur à l'état normal. Parmi les changements fonctionnels il faut également compter les discoordinations nerveuses provoquées par les effets de la substance nocive. La dystonie neurovégétative doit être considérée ici non pas comme une altération, mais comme un épuisement progressif des forces protectrices de l'organisme. Il en résulte que les doses limites des substances nocives dans l'atmosphère ont une identité ou analogie quant à la conception de la locution "un milieu de travail commode" ou "commodité de travail".

(c) par suite des effets nocifs il ne doit pas se produire des sensations de malaise causées par exemple par l'irritation des muqueuses ou des conjonctives et une surexitation de l'analyseur de l'odorat etc.

Les valeurs limites des doses nocives dans l'air doivent être toujours appliquées pour toute la journée de travail qui ne doit pas durer plus de 8 heures.

Selon la conception des USA, les valeurs limites doivent être considérées seulement comme moyen de controle du risque sanitaire et non comme une limite précise entre les concentrations inoffensives et dangereuses. Elles représentent en effet les conditions auxquelles peuvent être exposés quotidiennement tous les employés sans danger pour leur santé. Les valeurs indiquées se rapportent à une

concentration moyenne déterminée pour une certaine période au cours de la journée de travail normale. La quantité dont on peut dépasser ces valeurs pendant un temps court sans nuire à la santé depend de nombreux facteurs comme le caractère de la substance nocive, le fait que des concentrations très élevées appliquées même pendant une courte période peuvent causer un empoisonnement aigu, si les effets sont cumulatifs; cela dépend également de la fréquence et de la durée des périodes pendant lesquelles apparaissent les hautes concentrations. Ou, dans le tableau des valeurs limites on n'indique pas la valeur délimitant ces écarts de concentration. Les valeurs limites sont destinées à être appliquées dans le domaine de l'hygiène industrielle; le travailleur qui se sert de ces valeurs doit être très instruit de l'hygiène industrielle de façon qu'il puisse apprécier toutes les circonstances importantes et mettre en valeur leur signification sanitaire et tout particulièrement les courtes variations de concentration.

L'Union Soviétique publie également des tableaux des doses limites des vapeurs, poussières et gaz nocifs dans l'atmosphère des ateliers. Les valeurs les plus récentes ont été publiées le 10.1.1959 par l'inspecteur général sanitaire de l'U.R.S.S. Le texte joint au tableau note que les doses limites des substances nocives dans l'atmosphère des ateliers sont maxima et qu'il est impossible de les dépasser. Ces concentrations doivent être obligatoirement respectées, car elles ont été promulguées par l'inspection sanitaire d'État. Les doses limites ont donc un caractère obligatoire pour chaque atelier. Par ailleurs, on appelle atelier tout lieu où les travailleurs restent d'une façon permanente ou périodique afin d'observer et de diriger les processus de production. Si les opérations sont effectuées en différent lieux de la salle de travail le lieu de travail à considérer sera toute la salle. Cette conception est donc différente de la conception américaine.

Aux USA, les valeurs limites sont promulguées par la Conférence Gouvernementale Américaine des Hygiénistes Industriels. Mais on ne voit pas en quoi cet règlement est obligatoire, car il doit être appliqué par une autre organisation sanitaire legislative des USA. La rigueur de ce règlement hygiénique est certainement plus poussée en U.R.S.S. qu'aux États Unis si nous admettons que pour une certaine substance nocive donnée on applique la même valeur dans les deux pays, alors en U.R.S.S. on ne doit en aucune circonstance dépasser cette valeur sauf si l'inspection sanitaire d'État délivre une permission spéciale et cela uniquement dans le cas où les travailleurs feraient un très court séjour dans le milieu de travail. A remarquer toutefois qu'on ne définit pas précisément l'expression: très court sejour.

Aux USA (selon la définition de 1958), on admet certaines variations—mais pas définies en détail—autour concentrations limites. On doit certainement laisser assez de liberté en ce qui concerne l'appréciation de l'importance hygiénique de la variation autour des concentrations moyennes pendant toute la journée de travail. Selon notre opinion, il éxiste donc aussi bien en U.R.S.S. qu'aux USA une certaine insuffisance dans le fait qu'on admet même pour les substances assez toxiques, des exceptions à la règle et que la décision quant à l'importance de ces variations est laissée uniquement à l'hygiéniste qui s'occupe de surveillance hygiénique et se fie seulement à sa haute érudition de toxicologue.

En Czechoslovakia on laisse actuellement en vigueur les doses limites indiquées dans les réglements No. 3 intitulés "Instructions sur les conditions hygièniques pour l'édification des entreprises industrielles": la conception de la notion "concentration maximum tolérée" s'appuie encore à celle valable en U.R.S.S. Les

valeurs indiquées dans ces instructions sont utilisées d'une part pour le contrôle de la situation hygiénique dans les entreprises industrielles et d'autre part pour apprécier les projets des nouvelles entreprises. Le texte annexé au tableau des doses limites indique certaines restrictions à la validité des concentrations maximum tolérées: en effet, on indique par exemple que "s'il est nécessaire d'éxécuter un travail dans des concentrations supérieures que celles indiquées sur le tableau, des prescriptions spéciales doivent être appliquées pour la protection des travailleurs". Et plus loin on cite que "les exceptions dans ces concentrations maximum tolérées seront faites dans chacun des cas par l'hygiéniste régional sur instruction de l'hygiéniste principal". Ces imprécisions ont donné' suite à toute une série de difficultés quant à l'application pratique du contrôle de la pureté de l'atmosphère des ateliers par les organes du service hygiénique qui posséde chez nous le droit d'inspection, car c'est un organisme d'État. En conséquence, on a décidé ces temps derniers, de mieux définir certaines notions concernant le contrôle de la pureté de l'atmosphère de travail.

On tiendra compte pour cette raison:

(1) des concentrations maxima tolérées des gaz, des vapeurs nocives et des poussières toxiques qui seront considérées comme les valeurs moyennes (pendant la journée de travail). Elles ne devront pas être dépassées dans cette moyenne (de 8 heures):

(2) des concentrations maxima tolérées, de courte durée (de pointe) qui permettront d'obtenir des concentrations respectivement supérieures dans des intervalles de temps limités selon le caractère individuel de telle ou telle substance.

Mais pour les substances pour lesquelles on n'aura pas déterminé les concentrations maxima de courte durée, on appliquera même pour un temps plus court, la valeur donnée par la definition du point 1. Ces définitions permettront de faciliter notablement le procédé d'évaluation du point de vue hygiénique des résultats de l'analyse des échantillons d'air pris dans l'atmosphère de travail.

Les prescriptions hygiéniques qui seront révisées chez nous, montreront l'importance que nous devons constamment porter à l'analyse du degré de pollution de l'atmosphère dans les ateliers, où il pourrait menacer la santé des travailleurs par aspiration de cet air pollué. Généralement il s'agira d'ateliers où les travailleurs entrent en contact dans une plus grande mesure avec les substances nocives qui seront indiquées par un signe spécial dans les instructions hygiéniques (sur le tableau des concentrations acceptables au point de vue hygiénique). Par entrer en contact dans une plus grande mesure on entend que le travailleur est en contact avec les produits nocifs dans la production, au cours de leur apparition, pendant qu'il les travaillera ou les utilisera. La fréquence des analyses à faire dépendra du danger de santé réel apparaissant dans les ateliers et ce danger sera toujours évalué à part par les organisations du service de l'hygiène.

Donc avant de faire l'analyse, on prélèvera les divers échantillons d'air dans des temps et des lieux précisés à l'avance ou encore l'air de l'atmosphère de travail sera constamment analysé par des analyseurs-enregistreurs.

L'analyse des échantillons d'air sera effectuée par:

(1) le service d'hygiène qui utilise cette méthode pour les besoins de l'inspection d'hygiène du travail;

(2) par les experts de l'entreprise et des ateliers si cette obligation leur est confiée par l'organisation du service de l'hygiène. Ceci se produit habituellement dans les ateliers où l'étude systématique de la pureté de l'atmosphère est décisive pour la protection des travailleurs.

L'analyse des essais d'air prélèvés sera effectuée par une méthode approuvée par les organisations du service de l'hygiène; les appareils seront également soumis à contrôle.

L'organisation du service de l'hygiène décidera des endroits où devront être prélèves les échantillons d'air et il déterminera en outre le temps nécessaire à cette opération ceci pour chaque atelier dans lequel l'entreprise du contrôle elle-même sera chargée systématiquement de la pureté de l'atmosphère. Le temps de prélève-ment des échantillons d'air dépendra d'une part de la méthode analytique utilisée et d'autre part des changements cycliques du procédé de production ainsi que des activités des travailleurs. Dans ce cas, le service d'hygiène surveillera de temps en temps l'analyse effectuée par l'entreprise en y faisant faire des prélèvements des échantillons d'air par ses employés qui effectueront l'analyse. C'est le procédé que devra employer le service de l'hygiène avec chaque modification du procédé techno-logique ou des activités des travailleurs.

Si en un certain endroit on fait plusieurs prélèvements d'air pendant la journée de travail, il faudra alors que ces prélèvements soient effectués de telle façon qu'ils saisissent bien le cycle des opérations de travail typiques ou le cycle des procédés technologiques. Dans le cas où la contamination de l'atmosphère ne dépend pas des cycles de production ou des opérations de travail, il convient de répartir régulière-ment les prélèvements d'air durant toute la journée de travail. Mais en même temps, il ne faut pas oublier que l'analyse de l'atmosphère des ateliers sert à évaluer:

(1) la pureté hygiénique de l'atmosphère,

(2) le niveau hygiénique de la technologie de production,

(3) le niveau hygiénique des procédés et des opérations de travail.

Les concentrations acceptables des substances nocives au point de vue hygiènique dans l'atmosphère des ateliers seront déterminées en principe pour toute substance nocive pour laquelle on a élaboré une méthode analytique exacte ou pour les cas où il sera possible d'effectuer continuellement l'analyse de l'atmosphère à l'aide d'analyseurs. Ces substances nocives seront marquées d'un signe spécial dans le tableau des valeurs limites complété d'un renvoi à la méthode adoptée.

Les concentrations acceptables des substances nocives de l'atmosphère des ateliers seront également établies pour les substances pour lesquelles on n'a pas encore élaboré une méthode analytique convenable ou un moyen quelconque de mesure des concentrations. Ces valeurs seront appliquées dans les projets des nouvelles entreprises ou des nouvelles technologiques à titre de valeurs directrices. C'est à partir de cette base que l'on designera le renouvellement d'air horaire exigé pour le milieu de travail ou bien que l'on pourra juger s'il est nécessaire de rendre le procédé de production hermétique, de mécaniser, d'introduire l'automatisme dans les technologies productives, etc. Ces substances seront également marquées d'un signe spécial dans le tableau des doses limites.

Pour toute utilisation pratique des concentrations hygiéniquement acceptables, il faut préciser le sens de certaines notions:

(a) Par travail de chaque employé individuel on entend l'activité effectuée dans le procédé de production qui est indiquée en detail dans les prescriptions de travail du catalogue des salaires et dont les précisions sont décrites dans les directives de service et de travail valables pour une production donnée;

(b) Par journée de travail on entend la période prescrite par la loi. La durée de la journée de travail est au maximum 8 heures, soit 48 heures par semaine. Toute modification de la durée de travail avec les substances nocives devra être approuvée par le service de l'hygiène.

(c) Les concentrations des substances nocives hygiéniquement tolérées dans l'air sont celles de l'air que les employés respirent dans les ateliers. Les ateliers de travail sont les endroits où l'employé doit travailler selon les prescriptions du travail et des opérations. S'il s'avère impossible d'assurer la pureté de l'atmosphère dans les ateliers même avec des procédés techniques efficaces tel que l'échange total de l'air ou l'aération des lieux de travail, la séparation des espaces contaminés de lieux de travail etc., alors l'entreprise devra, selon les directives du service de l'hygiène, mettre en application des prescriptions de sécurité et d'hygiène spéciales relatives au séjour des employés en ces lieux, leur fournir un équipement protecteur des voies respiratoires ou installer des appareils de ventilation et d'aération transportables. Ceci est également valable en cas d'interruption ou de réparations des machines de production. Si on dépasse au cours de ces travaux la concentration moyenne hygiéniquement tolérée tout en tenant compte que dans ce cas il est interdit de dépasser les concentrations limites maximum tolérées pour une courte durée, alors il n'est permis de travailler dans cette atmosphère que pendant une période qui, par les calculs, nous donnera une valeur convenant à la valeur moyenne de la concentration admissible multipliée par huit. Dans ce cas il s'avère juste de considérer le travail dans ces conditions comme une journée entière de travail. Cependant, dans un tel milieu, on recommande d'organiser soigneusement le travail, de manière à ce que la cas extrême ne puisse être atteint.

En conséquence, il serait efficace d'organiser le travail de façon que le danger soit minimum pour les employés, d'intercaler dans la période de travail des pauses dans un milieu sain, de réduire la durée de travail dans les milieux où l'exposition des travailleurs vis à vis des substances toxiques est accrue.

REPORTS

Determination of Toxic Substances in the Atmosphere of Industrial Plants in Czechoslovakia

IN Czechoslovakia the control of air contaminants in industrial plants has been entrusted to the laboratories of Regional Hygiene and Epidemiology Stations as agents of the State Hygiene Inspectorate. In accordance with an order made by the head hygienist of the country, large industrial enterprises are required to carry out their own determinations of toxic substances in the atmosphere of their plants. In order to make the results of all laboratories comparable, they needed to be equipped with uniform instruments and to use similar analytical methods. The bulk of this preparatory work was given to the Institute of Industrial Hygiene and Occupational Diseases in Prague. The first stage consisted of providing a uniform scale of equipment for all hygiene stations. Apart from the instruments currently available, it was necessary to develop special methods for atmospheric sampling, to test them in particular situations and to introduce their serial manufacture. In this way, it has been possible to equip laboratories of the public hygiene service with standard types of grit absorbers and impingers, efficient sources of suction, sampling stands, holders for fixing membrane filters, gas meters, etc. All stations, without any exception, have already been equipped with a photometer and a polarograph.

With satisfactory instrumentation it was then possible to select standard analytical methods. Irrespective of whether they were new procedures or methods based on a known principle they had to be adjusted to the requirements of the hygiene service. When giving instructions, standard instrumental equipment was always taken into account. For instance: in all analytical methods involving absorption of the contaminant into a liquid, the application of one of three types of standard absorbers was considered and instructions given for the optimum volume of liquid, the correct flow and the minimum air volume to be aspirated in order to ascertain the hygienically significant concentration of toxic substance in the atmosphere. Quantitative retention in absorbers was verified in the laboratory by means of gas mixtures of defined composition.

In cases where it appears suitable, two analytical procedures are given, e.g. a colorimetric and a polarographic method. If both methods are available to the laboratory, the chemist may select between them according to the conditions appertaining, e.g. whether there are interfering factors or not. Since all hygiene stations in Czechoslovakia are equipped with direct indicating tubes for a preliminary determination of harmful contaminants, analytical methods must offer greater accuracy, particularly as they are often used to obtain technical data to be used by sanitation engineers, e.g. in designing or evaluating ventilating equipments.

The standard analytical methods used for controlling the purity of the atmosphere in industrial plants are to be published at the beginning of next year after approval by the Ministry of Health. They have been developed for the determination of the following contaminants: acetone, ammonia, aniline, antimony, arsenic, benzene, benzidine, beryllium, cadmium, carbon dioxide, carbon disulphide,

chlorobenzene, chlorine, chromium, chlorinated hydrocarbons, copper, dinitro-chlorobenzene, esters of acetic acid, esters of acrylic and methacrylic acids, fluorides, formaldehyde, gasoline, hexachlorocyclohexane, hydrogen cyanide, iron, lead, manganese, methanol, nitrobenzene, nitrous gases, pentachlorophenol, phenol, phosphine, styrene, sulphur dioxide, trichloroethylene, trinitrotoluene, etc. For the determination of carbon monoxide, an infra-red analyzer is recommended; for mercury vapour an ultra-violet one.

In order to compare results of air analyses to a still greater extent, efforts are made to attain standard procedures in co-operation with other countries. A start in this respect was a conference of chemists of the public hygiene services of Czecho-slovakia and Poland, held from the 24th to the 26th November, 1959 in Zakopané. On this occasion experiences gained in the field with analyses of industrial atmo-spheres were discussed and an attempt was made to exchange and mutually confirm methods for the analysis of toxic substances.

It would be desirable to extend the standardization of laboratory equipment and analytical methods to further countries.

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German-Austrian Engineers' Conference on Dust Measurement

THE 1960 annual conference of the dust section of the German engineers' association (Verein Deutscher Ingenieure), on "Trends of development in dust measurement", was organized in co-operation with the Austrian engineers' and architects' associa-tion and the Austrian centre for dust (silicosis) prevention. More than 600 delegates gathered in Vienna from 4 to 6 May, 1960, and the following papers were read.

(1) *The position in dust-measuring technique* by Dipl.-Ing. P. Noss, T.U.V. Essen e.V., Essen. A general introductory review for those new to the subject, with special reference to methods current in Germany and the tendency to recording instruments.

(2) *Dust deposition by thermal and pressure diffusion* by Prof. Dr. G. STETTER, one of the best-known German and Austrian dust physicists, of the 1st Physical Institute, Vienna University. The theoretical background explaining the force ex-perienced by a dust particle due to differential molecular bombardment in a tempera-ture or pressure gradient was given. The thermal effect has been widely used in dust-sampling instruments but is unlikely to be applicable to dust removal on a large scale, except possibly from highly-turbulent gas streams where there is an appre-ciable temperature gradient in the boundary layer. The pressure effect is unlikely to find useful application since the dust transport is always annulled by an eventual return movement of the air, but is of some academic interest because of its analogy to the thermal effect.

(3) *Studies on the precision of particle-size analysis* by Prof. Dr. Ing. K. RUMPF, Institute for Mechanical Instrument Technology, Karlsruhe, reviewed the various parameters for describing particle area, volume, diameter, falling-speed and the different ways in which size-distribution measurements could be presented;

and illustrated the different results apparently obtained using different parameters, by examples from sieve and sedimentation analysis.

(4) *Dust-measuring instruments with indication or registration of gravimetric concentration* by Prof. Dr.-Ing. T. GAST, dust-measurement laboratory of the Walsum Mining Company and Clausthal Mining Academy. This was certainly the outstanding paper of the conference as far as dust instrument technology was concerned, and was well illustrated by ciné films. Dr. GAST has spent many years developing "dust-balances" in which dust is deposited by electrostatic precipitation and the deposit weighed by a built-in torsion balance in which the re-balancing torque is recorded. Several versions have been developed according to the dust to be measured and the instrument techniques available. The latest model, compact, self-contained, and officially approved for use in gassy mines, is of great interest (see Fig. 1).

A small fan draws air at 1 l/min through an electrostatic precipitator chamber where the dust is deposited on a light vertical disk (½ in. diameter) which forms the pan of a torsion balance. After 1 or 5 min, as selected by a control, suction automatically ceases, the disk is freed from the chamber and a servo-motor, actuated by the out-of-balance current from a pair of coils, applies a restoring torque until balance is obtained. The motor movement is recorded on the chart, giving the weight of dust on the pan. By fitting an elutriator on the inlet, the coarse, non-respirable dust may be excluded. Full-scale deflection of the chart, 5 cm long, is 1 mg of dust on the pan; the sampling times of 1 and 5 min thus represent concentrations at full-scale of 1000 and 200 mg/m³; adequate reading can be made at 1/10 full-scale, i.e. 100 and 20 mg/m³; and 1/100 full-scale, or 1 and 0·2 mg/m³, can be detected. For low concentrations a longer sampling-time can be selected manually, e.g. 20 min to give 50 mg/m³ full-scale or 5 mg/m³ at 1/10 scale. (25 mg/m³ is roughly 1000 coal-dust particles, 1–5 μ, per cm³ of air.) After weighing, the dust is automatically wiped off the pan by a velvet-pad, which is itself then vacuum-cleaned, and the empty pan weighed again to give a zero, this cycle taking 1 min. Dust sampling then resumes. Variation in accumulator voltage has little effect on the balance.

Compactness has been achieved by the use of transistor circuits set in resin, blocks of circuit being replaceable on the unit principle. The balance is self-contained in power supply, consuming only 1 watt at 12 volts from lead-acid accumulators, weighs about 20 lb, and the housing is a horizontal cylinder about 6 in. diameter and 15 in. long, with a window through which the record may be seen. It is certainly the most refined instrument yet developed for dust-sampling in mines, and is to be manufactured by Sartorius of Göttingen. Adequate underground tests to establish confidence in the instrument are clearly desirable.

(5) *The Beta-apparatus, a new routine method of air-sampling with simple probes* by Dipl.-Ing. K. BREITLING, Dresden. In a written contribution to discussion, the difficulties of using complicated, compensating sampling-probes to maintain isokinetic sampling in a varying air-stream were described, and it was claimed that a procedure for using simple probes and achieving the same result had been evolved. Unfortunately the author did not attend and so no details are available. These probes would be used for sampling coarse dusts in air moving at speeds faster than those encountered in mine ventilation.

FIG. 1. The Gast Dust Balance for continuously recording airborne-dust concentrations in coal-mines. (*Photo. by Sartorius-Werke*).

(6) *Review of problems of dust-deposition measurement* by Dr.-Ing. K. SCHWARZ, T.U.V. Essen e.V., Essen. The German regulations on air pollution, passed in December 1959, gave extensive powers to the municipalities to proceed against offenders, but this could only be done if simple and reliable means of measurement were available. The German engineers' association (V.D.I.) commission on air pollution had already recommended the funnel deposit-gauge and the deposition foil as the most useful methods. Now, strict instructions for their application had to be prepared, in order that comparable results might be obtained wherever they were used. The next two papers describe studies to this end. The results of a systematic survey in Essen were presented.

(7) *Measurements of dust deposition* by Dr. M. DIEM, Karlsruhe Technical College. For a period of a year, deposit gauges used by different organizations in Germany operated together in one place. The reproducibility of a single instrument seemed to be about ± 20 per cent or less, and the mean values from different instruments were in fair agreement. The airborne-dust concentration was also measured by filter apparatus, and graphs of its correlation with the deposition rate were presented.

(8) *Practical results from dust-deposition measurements* by Prof. Dr. A. HELLER, Institute for Water, Soil and Air Hygiene, Berlin-Dahlem. Improved apparatus for analysing the soluble and insoluble materials washed out of the atmosphere by rain were described, together with diagrammatic presentation of the results of some surveys.

(9) *The work and aims of the Austrian Dust (Silicosis) Prevention Centre* by Ing. F. MARESCH, Vienna. This Centre, recently established with headquarters in Vienna and laboratories in Leoben, 100 miles away in the mining area, was in fact an association to which all organizations with an interest in silicotic dust belonged. The scientific activities received support from the 1st Physical Institute of Vienna University. An organization for routine dust-measurement had been set up, the mining, granite and foundry industries being of the most concern. This work would then form a basis for the application of dust-suppression measures.

(10) *Routine dust-monitoring* by Dipl.-Ing. W. KITZLER, Leoben. The Konimeter (mostly the Sartorius H.S. Standard version, occasionally the mining version) formed the basis of the Centre's dust measurement because of its simplicity and ease of use and evaluation and of the psychological value of a demonstrable dust sample. Dark-ground illumination was used for counting the particles. A filter apparatus took dust-samples for compositional analysis.

(11) *Dust-measurement in coal-mines* by Dr.-Ing. H. BREUER, Steinkohlenberg‾ bauverein, Essen, described the current German procedures in which a photo-metric estimate of dust composition in konimeter samples was combined with a concentration measurement by Tyndalloscope to classify working places in one of four dust-levels. To supplement these measurements a new "fine-dust filter appara-tus" had been developed in which a cyclone collected the coarser non-respirable dust and a membrane filter the fine pneumoconiosis-producing dust. The suction was about 10 l/min, by ejector driven from the mine compressed-air supply. The Stetter Tyndalloscope, which measures forward-scattered light between the semi-angles $1°$ and $2°$, now existed as a production prototype by Leitz of Wetzlar; the scattered light flux was said to give the total particle volume concentration in the air.

(12) *Methods of measurement in powder-metallurgy* by Dr. K. TORKAR, Institute for Inorganic and Physical Chemistry, Graz, described techniques for measuring surface, particle-size and activity of powders in bulk, which might also be of use for dust samples.

(13) *Origin, properties and determination of the sub-micron aerosols in smogs* by Prof. Dr. A. GOETZ, California Inst. of Technology (the only paper by a foreigner, but he a master of his subject). Although natural sources of particles 1 to $1/100\,\mu$ were widespread, man-made sources now predominated, though these aerosols underwent photo-chemical reactions and had a limited life. Smogs formed because these aerosols acted as condensation nuclei. The aerosols, by collecting oxidation products, can cause them to be deposited in the sensitive regions of the lung: hence the physiological reaction correlated better with atmospheric turbidity than with gas content.

(14) *Review of problems of radioactive dust-measurement* by Prof. Dr. J. A. SCHEDLING, 1st Physics Institute, Vienna University. The problems of sampling and measurement, the corrections of the measurement for absorption and background, and the interpretation of radiation spectrometry measurements, were described. The establishment of a radioactive material cycle, dust—earth—water—plant—animal—man, now increased the difficulty of interpretation.

(15) *Apparatus for the measurement of radioactive dust in work places* by Dr. Ing. D. HASENCLEVER, Dust Institute, Bonn. A very detailed description of sampling and radiation-detection apparatus, and analysis of measurements.

(16) *Radioactive pollution of the atmosphere* by Dr. G. SCHUMANN, 2nd Physics Institute, University of Heidelberg. The chief radioactive contaminant of the atmosphere was radon and thoron and decay products liberated from the earth's crust. Only slight contamination arose directly from cosmic radiation. Atomic bomb tests so far had only raised the total activity of the atmosphere by about 1 per cent. On the other hand, man-made activity was usually in atomic, not gaseous form, and deposited readily, on aerosols for example. In this way the behaviour of these atmospheric aerosols had been studied; their life was found to be about 1 month. Air-exchange between troposphere and stratosphere had also been studied by observations on aerosols and an annual variation, as yet not interpreted, had been discovered. The Carbon 14 content of the atmosphere had increased by 30 per cent due to atom-bomb tests, the Tritium content by a hundred-fold.

As engineers the V.D.I. members are naturally concerned more with dust extraction and air-cleaning in industry and the practical aspects of the necessary dust-measurement techniques, rather than with the fundamentals of dust physics. Nevertheless the very large attendance reflected the widespread interest in dust in Germany and Austria: it seemed that all persons and organizations concerned with dust, academic as well as industrial, were represented and this was a most useful feature of the conference. Although about fifteen other nations were represented, their delegates were only a few per cent of the total attendance, and more delegates and papers from other countries were officially invited for next year. These V.D.I. conferences would be more attractive to foreign visitors if the papers were circulated in advance so as to save time at the conference and allow the discussions to be

organized effectively. More attention might also be paid to the convenient arrangement of the conference hall.

The conference papers have been published in full in the German dust journal *Staub*, volume 20, pp. 241–324 (1960).

J. R. HODKINSON

Safety in Mines Research Establishment
Ministry of Power
Sheffield

BOOK REVIEW

Data sheets on dust collectors. Published by the British Steel Castings Research Association, East Bank Road, Sheffield, 2. Paper covers, 10 in. × 8 in. ix + 35 pp., 30/- postage paid.

THERE exists a considerable need for guidance in the selection of dust and fume extraction devices by purchasers who are confronted with a variety of designs to choose from. A step in this direction was the publication in 1957 of British Standard Specification 2831, "Methods of test for air filters used in air conditioning and general ventilation", which gives full details of tests which could profitably be applied to many of the extractors mentioned in the publication under review; rather surprisingly there is no mention of the British Standard anywhere in the book and the criteria of penetration printed are diverse indeed.

In spite of this lack of objective information on the most essential function of a dust extractor it has been deemed worth while to print graphs purporting to show the collection efficiency as a function of particle size for a dozen "typical" dust collectors from which it is stated that the overall efficiency and emission of any particular dust collector can be predicted if the grading of the dispersed material is known.

Theoretical curves are of interest when studying the design of dust equipment but those published are manifestly erroneous in trend for fine particles and provide no substitute for authentic test data at any size; the claim made on their behalf is tendentious and they are liable to mislead.

On the other hand, pressure drop data is given for all the 32 extractors listed and is clearly of value, as is the information regarding the whereabouts of installations so that prospective purchasers can see in action many of the examples listed.

The principle of operation of greatest importance in the extractors described in these data-sheets is particle-inertia which is exploited in a variety of ways, with and without the aid of water. Electrostatic devices are lacking, although included in the table of cost analysis and in the graphs of typical performance.

A fair amount of fundamental research on the trajectories and collision properties of aerosol particles has been carried out during the last ten years, but there is little to indicate that it has been applied to extractor design which reflects strongly an unilluminated trial and error approach. This is not surprising because academic research in the aerosol field has not been supported by the firms whose products are listed in this publication.

C. N. DAVIES

ERRATUM

HUBERT ANTWEILER, observations about a histamine liberating substance in cotton dust. *Ann. Occup. Hyg.* **2**, 152–156 (1960).

On p. 156 Reference:

BOUHUYS, A., LINDELL, S. E. and LUNDIN, G. (1959) *Medical Research Council's Panel on Byssinosis*, London (in the press).

should read:

BOUHUYS, A., LINDELL, S. E. and LUNDIN, G. (1960) *Brit. Med. J.* (i) 324.

PREDICTING THE DRY AND WET BULB TEMPERATURES OF COAL MINE AIRFLOW

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Abstract—In the development of the deeper British coal seams there are three basic climatic questions to which the mining engineer requires answers, namely, what will be the working temperatures, how will man's output of work be affected by such temperatures, and what amelioration, if any, will be required. These questions are discussed in a sequence appropriate to the opening up and development of a mine, covering shaft sinking, advancing headings and fully ventilated roads and coal faces. The facts that are required by the mining engineer when calculating the temperatures of mine air are listed and, where possible, the methods of predicting the temperatures are described. The lines on which research is proceeding to extend the present limited knowledge are indicated. A brief reference is made to the special climatic problems associated with the continuous machine mining of headings.

LIST OF SYMBOLS USED IN THE TEXT

ρ	Density of strata
c	Specific heat of strata
k	Thermal conductivity of strata
K	Thermal diffusivity $(= k/c\rho)$
θ_r	Strata temperature at a point distant r from the centre of the airway
θ_v	Virgin strata temperature
θ_s	Surface temperature of the strata surrounding an airway
θ_o	Temperature of the air entering a force ventilating duct or roadway
θ_l	Temperature of the air leaving a force ventilating duct
θ_x	Temperature of the air at a distance x along an airway
Q	Airflow
R	Radius of a ventilating duct
L	Thickness of the material in a ventilating duct, including thermal insulation where appropriate
r	Radius to a point in the strata from the axis of an airway
a	Radius of the airway, assumed circular in cross-section
t	Time
h	Heat transfer coefficient for the boundary between strata and air
x	Distance along an airway

INTRODUCTION

To obtain coal from the deeper British seams it is important to know what the dry and wet bulb temperatures will be in the hot, humid conditions where the men will work. It is also necessary to know how such conditions affect man's output of work and what methods, if any, would be required, and at what cost, to make the environment acceptable.

These questions arise not only in coal mining, but also in metalliferous and salt mining, and there is world-wide interest in their solution. Until recently the predominant interest has been in the provision of air conditioning plant, mainly

in South Africa, Belgium and Germany, and much of what has been done has recently been reviewed by BROMILOW (1956). Means of predicting mine air temperatures have received much attention in the last few years, the approach to the problem being an empirical study such as is illustrated by the recent surveys of LAMBRECHTS (1959) or the more fundamental theoretical treatments of DE BRAAF (1951) and WILES (1959). Although this paper is mainly concerned with the problem of predicting air temperatures, comments are included on the upper working limit of temperature, and on the general principles to be adopted when air conditioning British coal mines.

(1) *The upper limit of temperature in man's working environment*

There is no doubt that the hot, humid conditions of the deeper workings affect man's output of work and it is only by knowing his limitations that any prediction of working temperatures can usefully indicate at what time and at what cost special ameliorative methods will be required.

In British coal mines there are, as yet, no statutory limits of dry and wet bulb temperature, but it is now recognized that there should be some compensation for working above whatever limits are eventually decided. In the German salt mines in the Clausthal-Zellerfeld district (NIEDERSÄCHSISCHES MINISTERIALBLATT, 1959) the working hours are limited and the minimum airflow is stipulated. Where personnel are exposed for at least 3 hr/day to a climate where the aggregate of 0·1 dry bulb and 0·9 wet bulb temperature exceeds 30 °C (86 °F) the daily net maximum working hours are 4. If for a minimum period of 4 hr/day the wet bulb temperature is over 28 °C (82 °F) and the dry bulb temperature 30 °C (86 °F) the net working hours are 6. Even with 5½ hr/day in a dry bulb temperature over 28 °C (82 °F) the working hours are limited to 7. Above 32 °C (90 °F) wet bulb temperature work can only be done in cases of emergency or by special permission of the Inspectorate. Among the additional conditions that must be fulfilled an air velocity of at least 0·5 m/sec (100 ft/min) at a minimum flow of 6 m³/min (210 ft³/min) per man is required.

A convenient and much-used method of assessing the climatic value of a given airflow is by means of the effective temperature corrected for radiant heat where necessary. This temperature is defined in a book of reference by BEDFORD (1946) which includes charts whereby it can be evaluated from the dry and wet bulb temperatures of the air, taking into account the air velocity. Recent work, quoted by LIND (1960), gives 27 °C (81 °F) as the upper limit of the effective temperature for work in the Royal Navy. LIND compares the work of the coal miner with that of the naval man and shows that the conditions for the former are almost all more exacting, and concludes that any limit for the effective temperature in coal mining may well be less than 27 °C (81 °F). Until the acceptable limiting conditions for British coal mines have been determined there will always be a difficulty in the interpretation of mine air temperature data. Meanwhile, until these limits are obtained it is necessary to adopt some figure, even if arbitrarily chosen and approximate in value, whereby mine air temperature data can be judged. It is also necessary to be able to relate such a figure to the dry bulb temperature which is the temperature mainly considered by the engineer in the design of air conditioning plant.

It seems reasonable, in the light of present knowledge, to take the limit as

being an effective temperature in the region of 27–29 °C (80–85 °F). On this basis the relationship between the dry bulb temperature and air velocity can be drawn as shown in Fig. 1. The full lines are drawn for an effective temperature of 29·5 °C
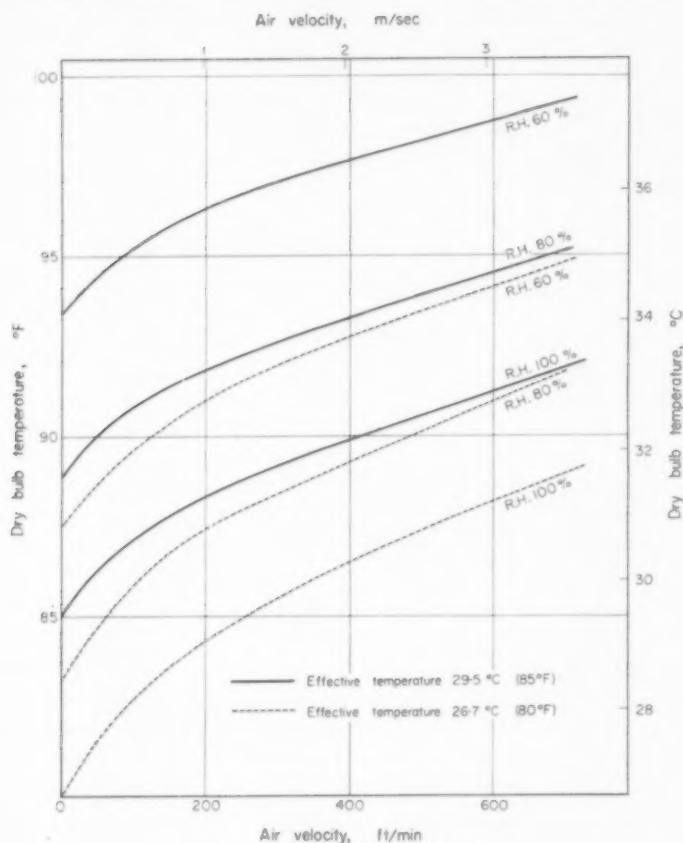
FIG. 1. The variation of dry bulb temperature with air velocity at constant effective temperature.

(85 °F). The broken lines are for an effective temperature of 26·7 °C (80 °F). There are three lines for each temperature at relative humidities (r.h.) of 60, 80 and 100 per cent. The graphs on the figure can be used to estimate the required dry bulb temperature of an airflow of known velocity if the airflow is to have an effective temperature near or within the suggested range. For example, near the face of an advancing heading where the general body of the return air will be at low velocity, say 0·2 m/sec (40 ft/min), if the effective temperature is not to exceed 29·5 °C (85 °F) then the dry bulb temperature must be no greater than 30 °C (86 °F) if the air is saturated or no greater than 34·5 °C (94 °F) if the air has a relative humidity of 60 per cent. When the air velocity is higher, say, 1·5 m/sec (300 ft/min) the same limiting dry bulb temperature of 30 °C (86 °F) in saturated air reduces the effective temperature to 26·7 °C (80 °F). A relative humidity of 60 per cent in air of the same velocity would permit the dry bulb temperature to

rise as high as 33 °C (92 °F). Graphs, such as those shown in Fig. 1, are needed to calculate the limiting dry bulb temperatures if the limiting effective temperature is to be the criterion of the suitability of a mine airflow.

2. *Information that is required when a new deep mine is developed*

An immediate need for the prediction of mine air temperatures in Great Britain occurs in the development programme being carried out by the National Coal Board in North Staffordshire. Figure 2 shows the variation with depth of cover of
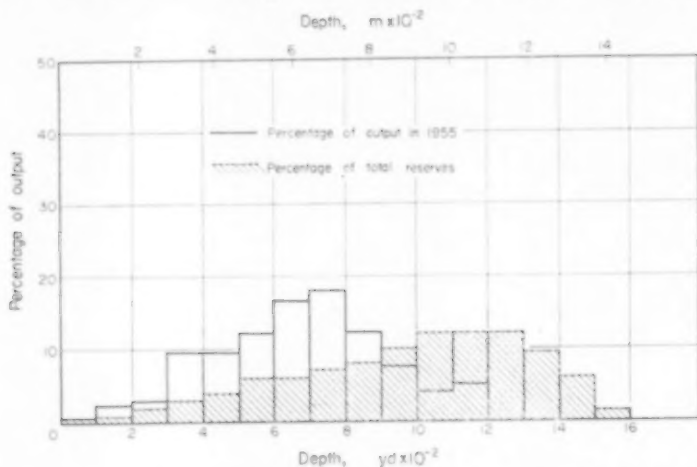
FIG. 2. The variation with depth of the output and the reserves of coal in North Staffordshire.

the output of coal in 1955 in this area compared with the reserves in that area. Most of the 1955 output came from depths around 640 m (700 yd) but over half the reserves lie below 910 m (1000 yd). The greater depths will mean higher strata temperatures, and already virgin temperatures above 38 °C (100 °F) have been measured. Clearly, among the early information that is required in a deep mine development programme is an accurate knowledge of the virgin strata temperature and, especially, how this temperature varies with depth of cover. All the facts that can be gathered concerning the thermal properties of the strata are also needed for any calculation of strata heat flow. Temperatures at the working face of each deep heading as it advances must be predicted, and the distance to which a heading can go before reaching the limiting effective temperature should be determined. It follows that the conditions for the most effective ventilation system for a heading must be laid down, and, if the limiting temperature is likely to be exceeded before the heading is completed, provision must be made for special air conditioning plant.

Once a heading is completed and becomes a fully ventilated main roadway the strata surrounding it will be cooled at a greater rate by the larger, cooler airflow. The rise in dry bulb temperature of this airflow as it passes along this roadway, complicated as it is by the pickup of moisture, especially in the regions of water sprays, wet drilling and strata leakage, is then required. The main intake air splits and passes along secondary roads to various coal faces, and somewhat different calculations are used to determine the further rise in temperature along these roads.

A good principle to adopt when supplying air to a coal face is to ensure that the air reaches the inbye end of the face of such a quality that whatever happens along the face the air leaves it at or below the limiting effective temperature. Much can be done to minimize the increase in temperature along a face but, even so, it is still imperative to prescribe the conditions which are needed for the air at the face intake to be of adequate quality.

The climatic problems that are of most importance when a new mine is developed have been described above in something like the order in which they may occur and it is broadly on these lines that the development programme in North Staffordshire is being studied.
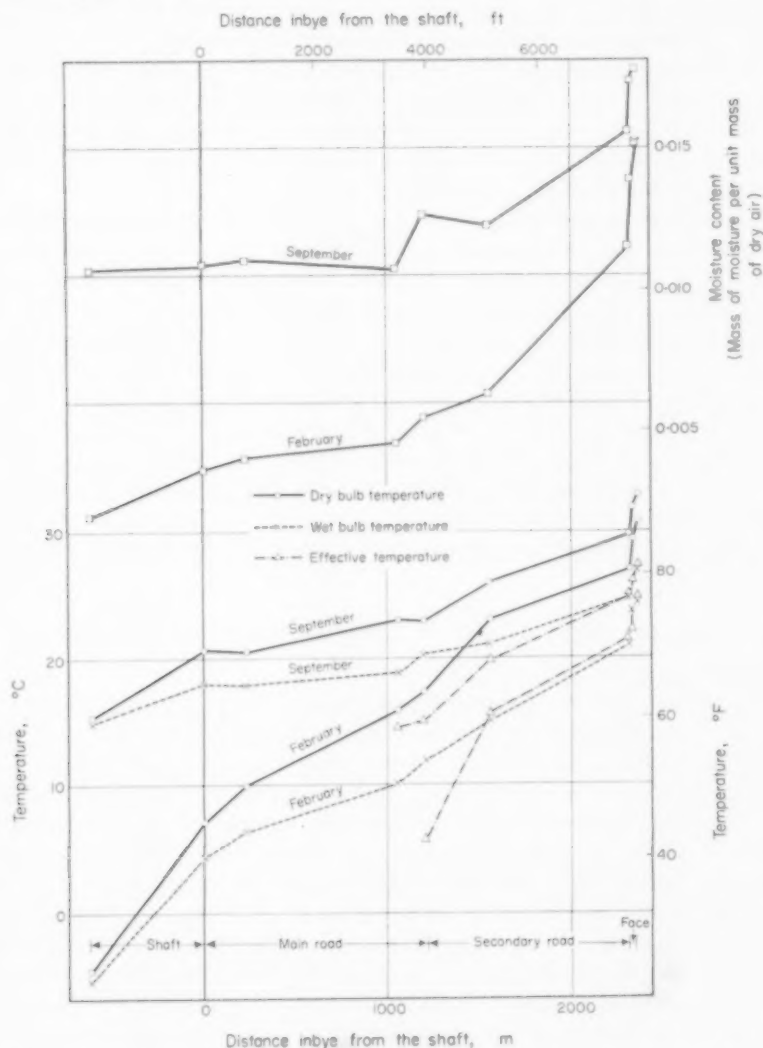
FIG. 3. Temperatures and moisture content of the airflow to 20's face at Sneyd Colliery.

3. *A recent typical underground survey of temperature*

Figure 3 shows some of the results from a survey carried out in North Stafford-shire in 1956 by the Scientific Department of the National Coal Board. It shows the dry and wet bulb temperatures, the effective temperature and the moisture content of the airflow passing to 20's face at Sneyd Colliery, the lower of each pair of graphs being for a day in February and the higher for a day in September of the same year. The figure also shows the extent of the main road before the main intake airflow was split and the length of the secondary road before reaching the face. The depth of cover at the face was about 1040 m (3400 ft) with a virgin strata temperature of 40 °C (104 °F). Although no general conclusions should be drawn from a single example such as this one there are several features of interest which are typical of the problem being tackled in North Staffordshire.

The most rapid increase in each of the three temperatures and in the moisture content takes place on the face. The secondary road is the region where the next largest gradients in the temperatures and moisture content occur and it is of interest that the increase in effective temperature was partly due to the low air velocity, about 0·8 m/sec (160 ft/min), along this road.

The seasonal differences between the dry and wet bulb temperatures and moisture content are very marked, and the differences, in this example, remain significant right to the outbye end of the face. There is little gain of moisture along the main road in either summer or winter, probably because at the time of the measurements the air entered the shaft almost saturated. The expected and marked increase in the dry and wet bulb temperatures of the air in the downcast shaft in winter is evident. The effective temperature in the middle of the face in winter was 22 °C (71 °F) and in summer it was 26 °C (79 °F), a figure which must be close to any limiting value. Surveys such as this one illustrate the need for a comprehensive understanding of the heat and humidity problem. From a practical point of view it is convenient to examine the problem in separate sections appropriate to the various stages of progress as a new mine is conceived, opened up and developed.

INFORMATION AVAILABLE PRIOR TO SHAFT SINKING

(1) *Thermal properties of the strata*

Boreholes are drilled downwards from the surface of the earth to locate the coal seams and determine the nature of nearby strata. It is possible to measure the thermal properties of a sample taken from a borehole, including the density, ρ, the specific heat, c, and thermal conductivity, k, from which the thermal diffusivity can be obtained. Values of these variables are required when calculating strata heat flow as well as the effect of moisture on them over a period of time. The big disadvantage with borehole samples when measured in the laboratory is that they are not necessarily representative of the same strata when *in situ* underground. The moisture content may have altered during coring of the sample and its subsequent move to the laboratory; the drilling, extraction and preparation of the sample for any measurement may have changed its structure. The thermal conductivity will be dependent on the direction of heat flow with reference to the bedding planes in the strata. If it is measured normal or parallel to the planes the further question arises as to how practical use is made of such measurements for

the non-homogeneous, moist strata around an underground airway whose planes lie at a variety of angles to the axis of the airway.

A laboratory study of the thermal properties of typical British coal mine strata has recently been completed by LOMAX (1957) and some of the factors mentioned above have been examined for a number of coal measure rocks, excluding coal. The general effect of moisture on the thermal diffusivity and thermal conductivity of strata is indicated in Fig. 4, which is based on LOMAX's results. The figure includes results for various rocks, most of which were measured along and at right angles to the bedding planes. Even so, it would appear to be sufficient to assume a linear relationship between the percentage increase in either of the two properties and the percentage moisture absorbed at saturation, as indicated in Fig. 4. There is considerable scatter about such lines, as the figure shows, but an inaccuracy in thermal conductivity or diffusivity does not directly affect the heat flow in the same proportion. It is suggested that the lines in Fig. 4 be used, at any rate in the first instance, to obtain the diffusivity and the conductivity for substitution in any formulae for the prediction of mine air temperatures.

Samples of the strata, from a survey borehole, are prepared and dried and their diffusivities and conductivities measured, measurements in the dry state being relatively simple and rapid. An average value appropriate to the strata surrounding
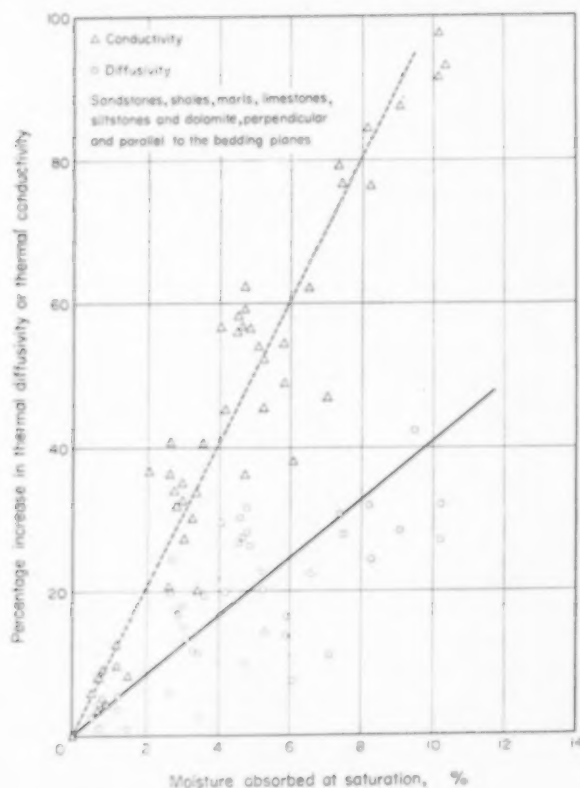

FIG. 4. Effect of moisture on the thermal properties of rocks.

the particular part of an airway under consideration is then obtained and the increase in this value is estimated from Fig. 4 for the saturated state, the average percentage moisture capable of being absorbed by the sample having been measured. This yields a representative value for diffusivity or conductivity on the assumption that the underground strata are saturated. The procedure is crude, but has the advantage of simplicity and copes with an otherwise unsolved problem.

(2) *Virgin strata temperature*

Survey boreholes can also be used to obtain values of the virgin strata temperature (θ_v), using the technique of COOPER and JONES (1959) for calculating θ_v at various depths of cover from measurements of the temperature of the drilling fluid near the bottom of the borehole at various stages as it progresses downwards. Further information about θ_v can be obtained if other coal mines are already in existence nearby; although the roadways in these mines are no longer surrounded by virgin strata, satisfactory results are obtained from measurements in an advancing coal face using the method of HARRIS and JONES (1959).

Figure 5 shows the results of recent measurements of the virgin strata temperature in Staffordshire using both the underground and survey borehole techniques. (The lines drawn on the figure only indicate the trends of the results.) In South Staffordshire the geothermic gradient changes from about 55 to 26 m/°C (100 to 48 ft/°F) and in North Staffordshire there is a similar change from about 42 to 24 m/°C (76 to 44 ft/°F) when proceeding to a depth of cover of 1070 m (3500 ft). It is obviously quite wrong to take a single figure for the geothermic gradient over the whole depth of working under consideration, and a graph showing the variation of θ_v with depth is essential. Such a change in the geothermic gradient as is indicated in Fig. 5 can be explained by a reduction in the thermal conductivity of the strata in the lower coal measures.

Figure 5 also illustrates the need to measure θ_v, since measurements taken at a certain depth of cover in one region do not necessarily hold at the same depth in another region. This is shown by the difference that exists between North and South Staffordshire down to about 750 m (2500 ft). It is also illustrated by the measurements of temperature at Victoria Colliery in North Staffordshire which are very much lower than other values for North Staffordshire, probably owing to the fact that extensive workings have taken, and are still taking, place there, causing considerable, permanent cooling of the strata.

With prior knowledge of the disposition, thermal properties and virgin temperature of the strata, it is possible to consider the working temperatures that may occur in the airways as they are opened up and developed. The sinking of a shaft to depths as great as 1000 m (3300 ft) does not produce uncomfortable temperatures until the lowest depths are reached where the virgin strata temperatures are highest and the auxiliary ventilation system less able to maintain a low effective temperature. However, the cooling of the strata around the shaft, which commences when the shaft carries something like its normal airflow, and other factors concerned with the passage of the air down the shaft, are important, as is the cooling of the strata surrounding main airways, but the first need as the mine is opened up is to be able to predict the working temperatures at the faces of the headings as they advance from the newly sunk shaft.
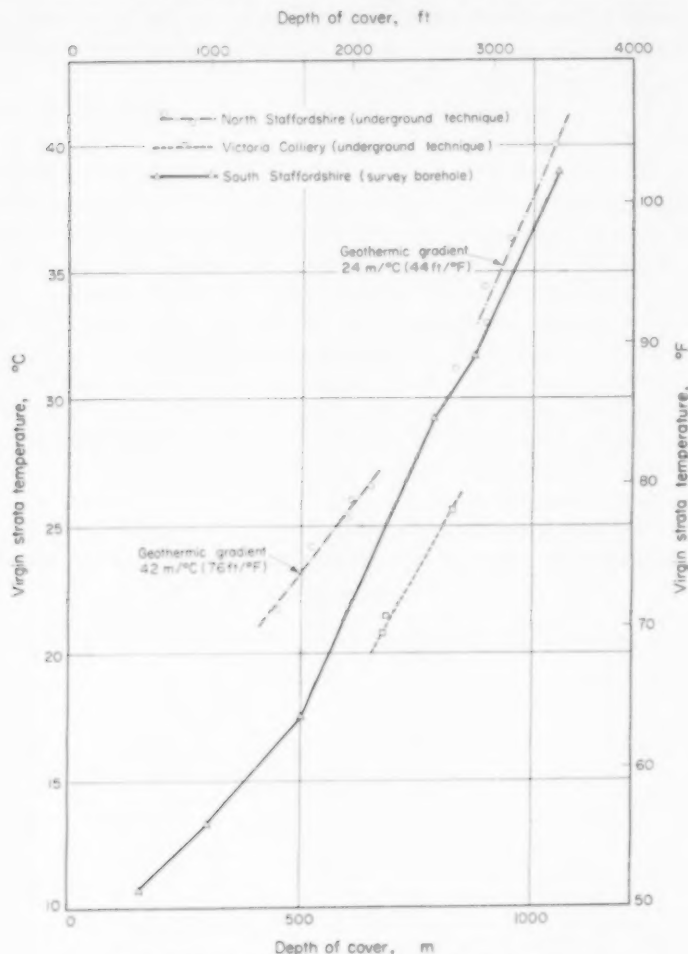
FIG. 5. Virgin strata temperature in Staffordshire.

TEMPERATURES AT THE WORKING FACES IN HEADINGS

A heading is usually ventilated by a forcing system, in which air is blown along a duct to the working face, although exhaust systems in which the air is sucked from the face, or a combination of both systems, are also used. For the achievement of the lowest effective temperature forcing systems are preferable. Air is taken to the face along a duct without pickup of moisture; although there is an increase in the moisture content of the air between the duct discharge and the face, the resultant moisture content is less than would occur if the same heading were exhaust-ventilated, for, in the latter case, the air would gather moisture for the full length of the heading. It is also possible to insulate thermally a forcing duct system, even after installation, but nothing can be done to reduce heat transfer to the intake air in an exhaust system. Naturally, a duct system is more satisfactory if it has a low leakage coefficient in order to minimize the fan power required to deliver the

required quantity of air. Given a forcing duct system the problem becomes one of predicting the discharge air temperatures for such a system as the heading advances.

(1) *Heat transfer to a forcing ventilation system*

A forcing duct system carrying air to the face of a heading receives heat by radiation from the surrounding warmer strata and by convection from the warmer air returning along the heading outside the duct. The theoretical equations that arise when this problem is formulated to include ducts which leak and surrounding strata which cools with time are complex, but they have been solved on an I.B.M. 650 computer by JORDAN (1960). The solutions are being tested with a series of underground experiments and will form the basis of a later article.

Meanwhile, a simpler mathematical approach has been completed by JONES and SHUTTLEWORTH (1960) which can be applied to a duct with little or no leakage, in a heading whose strata surface temperature, θ_s, is assumed to be everywhere the same at a particular instant of time but which varies with time. The relationship in Fig. 6 was obtained by means of experiments in force-ventilated headings. The graph shows the variation with time of the dimensionless ratio $(\theta_s - \theta_o)/(\theta_v - \theta_o)$ where θ_o is the temperature of the air as it enters the forcing duct. Once θ_o and θ_v are measured, the value of θ_s can be determined for the particular length of heading under consideration. Figure 6 was drawn from observations in headings where

Airflow about 140 m³/min (5000 ft³/min)
Duct diameter 61 to 76 cm (24 to 30 in)
Rate of advance 9m/week (10 yd/week)
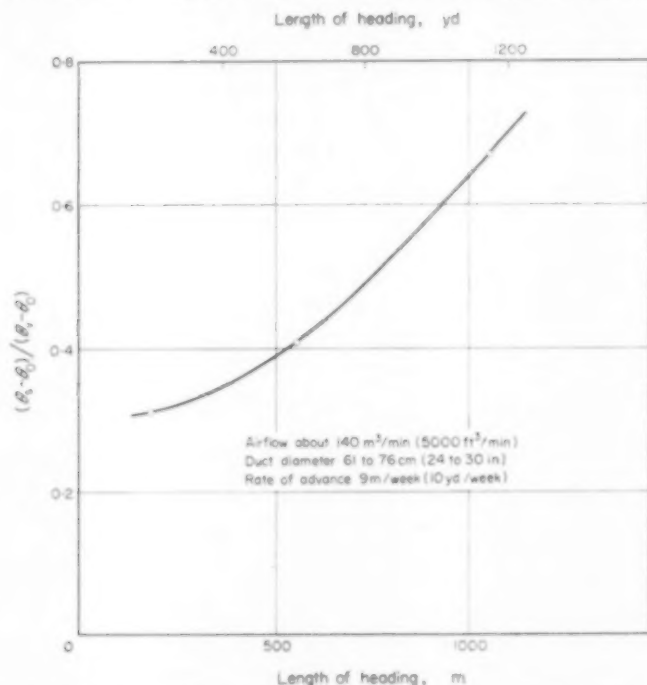
FIG. 6. A graph for calculating the strata surface temperature in an advancing heading with forced ventilation.

the steel duct was 61–76 cm (24–30 in.) in diameter, the airflow was about 140 m³/min (5000 ft³/min), the cross-sectional area of the heading was about 9–14 m² (100–150 ft²) and the rate of advance about 9 m/week (10 yd/week).

Simple theory gives graphs of the ratio $(\theta_l - \theta_o)/(\theta_s - \theta_o)$ as the heading advances (Fig. 7), where θ_l is the temperature of the air as it is discharged from the duct.

Length to which heading has advanced,   ft
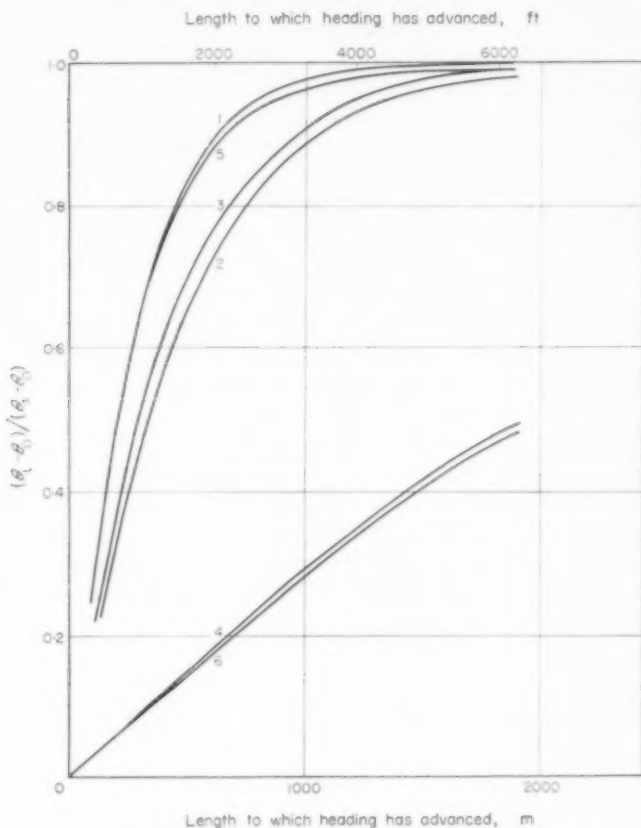
FIG. 7. Discharge air temperature for a forcing duct system.

The six curves on the figure represent different conditions and illustrate a number of useful features. The difference between curves 1 and 2 is due to a change in the airflow which appears to be advantageous insofar as it reduces the value of the ratio $(\theta_l - \theta_o)/(\theta_s - \theta_o)$ and hence θ_l. Increasing the duct radius between curves 2 and 3 causes a small increase in the temperature ratio. However, there are other important features which should be considered here. The return air in the heading achieves a temperature very close to the strata surface temperature, θ_s, and the heat extracted from the heading is proportional to the product $Q(\theta_s - \theta_o)$ where Q is the airflow. The value of θ_s at any instant will be influenced by the quantity of air which has passed along the heading, being lower for greater amounts of air. A high airflow will therefore have the long term effect of reducing the value of θ_s in the temperature ratio in addition to the immediate effect of reducing the ratio itself. Each brings about a reduction in the discharge air temperature.

A second important factor, of course, is the value of θ_o, the intake air temperature. By lowering θ_o the discharge air temperature is reduced. In addition, a

lower value of θ_o will have the long term advantage of a reduction in θ_s because the airflow, if cooler, can extract more heat from the strata.

In arriving at a value of θ_o account should be taken of the energy added to the intake air by the power of the fan which appears as heat in the air immediately after the fan. JONES and SHUTTLEWORTH have published a table of corrections which should be made to give θ_o when this heat is included and an example based on them is of interest here. An airflow of 284 m³/min (10 000 ft³/min) at 21·1 °C (70 °F) entering a fan in a duct of length 1220 m (4000 ft) and 76 cm (30 in.) diameter would have $\theta_o = 23\cdot1$ °C (73·6 °F) and $\theta_l = 31\cdot8$°C (89·2 °F) when $\theta_s = 32\cdot2$ °C (90 °F). Changing the duct size to 61 cm (24 in.) changes θ_o to 27·1 °C (80·8 °F) while θ_l is only changed to 31·9 °C (89·4 °F). Because the intake temperature is higher in the second case the air, in travelling along the duct, absorbs less heat from the surroundings; the rise in temperature along the duct is therefore smaller than in the case of the larger duct, the discharge air temperatures being similar in both cases.

The most marked reduction in the temperature ratio occurs when a duct is thermally lagged, curves 2 and 4 (Fig. 7). The further possibility that a heading can be driven in somewhat cooler strata is considered in curves 1 and 5 and also curves 4 and 6. In both cases the strata surface temperature difference of about 5 °C (10 °F) shows little change in the temperature ratio. Nevertheless, the discharge air temperature will be lower by an amount which can be almost equal to the reduction in the strata surface temperature, depending on the length of the heading and whether the duct is thermally insulated. If a choice exists between two depths of cover then the shallower drivage should be adopted, but if a thermally insulated duct is to be installed it is immaterial which level is used. The graphs in Figs. 6 and 7 have already been used in a few advancing headings for the calculation of the discharge air temperature, and the calculated values were within 0·5 °C (1 °F) of the observed values.

(2) Moisture pick-up at the face

The air that is discharged from a forcing duct creates a circulatory airflow pattern between the duct discharge and the face; polluted air, returning from the face, is readily entrained in this as can be demonstrated by a tracer technique in a laboratory scale model using water as the fluid. It has also been observed by HITCHCOCK et al. (1958) during measurements of the moisture content near the face of headings. More recent surveys have always shown an increase in the moisture content between duct and face by an amount depending on the operations at the face. Loading material when sprayed with water, for example, gives a big increase. Although water is used for dust suppression it should not be used excessively. It may even be possible to reduce the face moisture content by establishing a ventilation system which minimizes recirculation and the associated moisture pick-up.

(3) Air conditioning for forcing ventilation systems in headings

When a heading commences its advance it may not be necessary to provide the duct with thermal insulation; as the heading reaches greater length the limiting effective temperature might be exceeded and insulation would then be a means of improving conditions. A method of doing this would be to wrap the suspended duct with a suitable material having a low thermal conductivity, say, about 0·00008

cal/cm² sec °C/cm (0·02 B.t.u./ft² hr °F/ft); its thickness need not be more than 4 cm (1·5 in.). The material must be non-inflammable, unaffected by water and capable of withstanding reasonably rough treatment. Tests of various likely materials are required, paying due attention to the economic aspects, but glass fibre subsequently cocooned with sprayed plastic paint may provide an effective solution.

With a long heading, of some 1000 m (1100 yd) or more, in strata with virgin temperatures greater than 35 °C (95 °F) discharge air temperatures in excess of 24 °C (75 °F) can be expected, even with thermally insulated ducts of large diameter carrying a large airflow. If the limiting effective temperature is exceeded under these conditions further amelioration can be achieved by the use of a refrigerator of the Freon type similar to that already studied in a Kent colliery by HITCHCOCK et al. (1958). The most efficient use of such a refrigerator is achieved when it is as near as possible to the discharge end of the duct, although this may necessitate passing the cooling water to the condenser along thermally insulated pipes. Where facilities permit, warm condenser water can be pumped out of the mine and replaced by cooler water from the surface. If no main water supply is available, another system of removing the extracted heat is required. The warm condenser water is pumped out of the heading to a water-to-air heat exchanger placed in an airstream with the required temperature. This exchanger, the condenser and two pipes will constitute a closed re-circulatory water system which transfers the heat extracted from the face of the heading to the airstream. If possible, it is desirable to dispose of the heat in return air since this warmer, less dense airflow requires less fan power.

THE EFFECTS OF MOISTURE AND STRATA HEAT ON ROADWAY AIRFLOW

(1) *Some general considerations*

Apart from the facts that the strata surrounding a shaft have higher temperatures at greater depth and that the airflow is heated by autocompression as it passes down the shaft, the flow of heat into and out of the strata surrounding the shaft is similar to that occurring around the main and secondary roadways. In fact, thin sections of it, when circular in shape, conform to the theoretical model for heat flow from a homogeneous medium into a hollow cylinder containing air at constant temperature. The variables which affect the flow of heat within the strata include (i) the virgin strata temperature, (ii) the physical properties of the rock such as its moisture content and thermal diffusivity, (iii) the non-homogeneity of the strata, especially the layered nature of its formation and its crack-structure and (iv) the previous history of the strata heating or cooling. Variables which affect the flow of heat at the boundary between the strata and the passing airflow are (i) the moisture content and temperature of the air and their variations along the airway and also with time, (ii) the air quantity or velocity, (iii) evaporation or condensation of moisture at the strata surface, (iv) the size, shape and surface roughness of the airway and (v) the surface temperature. Other factors, such as the oxidation of exposed coal and those of a man-made nature, such as heat from machinery or compressed air pipes or the evaporation of water from sprays and transported moist material are also important but require separate consideration.

(2) *The cylindrical theory for strata heat flow*

Recent work in homogeneous strata by DE BRAAF (1951) and in cross measure strata by HITCHCOCK and JONES (1958) has supported the contention that an underground roadway through non-homogeneous material can be treated as a hollow cylinder surrounded by a homogeneous material of unknown but uniform thermal properties. The equation for the temperature at any point in the strata at a distance r from the centre of the cylinder (or centre of a thin cross-section of the airway assumed circular) at a time t is given by JAEGER (1942), and this can be written in the form.

$$\frac{\theta_r - \theta_o}{\theta_v - \theta_o} = \phi\left(\frac{r}{a}, \frac{kt}{c\rho a^2}, \frac{ah}{k}\right)$$

where θ_o is the constant air temperature in the section of airway.

To ensure that this expression satisfactorily includes all the variables which affect strata heat flow and to produce quickly graphs of the above function, which contains an integral whose evaluation requires considerable computing, a scale model technique has been adopted by HITCHCOCK and NORTHOVER (1960). In the model, the strata surrounding a cross-section of an underground airway is represented by a thin disc of epoxide resin, through the centre of which air is passed at a temperature which is constant and different from the initial temperature of the disc. A specially designed guard system ensures that heat flows only in the plane of the disc. Thermocouples are spaced in the disc so that temperature distributions can be recorded as the strata temperatures progressively change owing to the effect of the airstream. The model and its ancillary equipment have been made so that the quantity and temperature of the airflow can be changed. The shape, size and roughness of the airway and the thermal properties of the strata, including cross-measures, can also be varied. Other advantages of the model technique include the fact that the scaling characteristics permit laboratory examination in a few hours of phenomena which may take many years underground and the variables can be properly controlled and studied separately, an almost impossible task underground. Figure 8 shows typical model curves of the temperature ratio
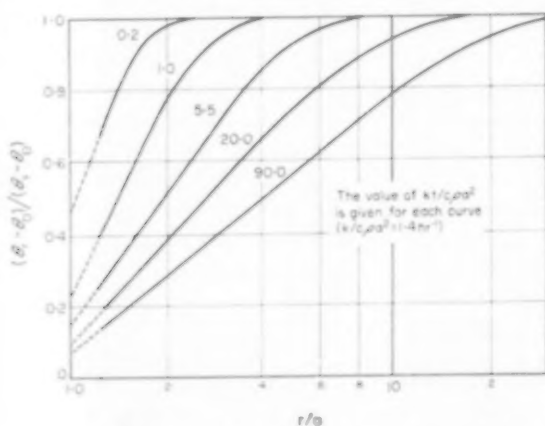
FIG. 8. Temperature–distance distribution with time for a cylindrical airway.

$(\theta_r - \theta_o)/(\theta_v - \theta_o)$ plotted against the dimensionless ratio r/a for a series of times t. It is easy to see the progressive cooling of the strata around a cylindrical airway from the time $t = 0$ when $(\theta_r - \theta_o)/(\theta_v - \theta_o)$ is everywhere unity to the time $t = 64$ hr $(kt/c\rho a^2 = 90)$ when the cooling has progressed into the strata to a distance of some thirty times the roadway radius. The curves have been extrapolated to the value $r/a = 1$ and the value of the temperature ratio there corresponds to that for the surface temperature of the strata at its boundary with the airflow. The same data are plotted in another way in Fig. 9 where it is easier to see the change in temperature
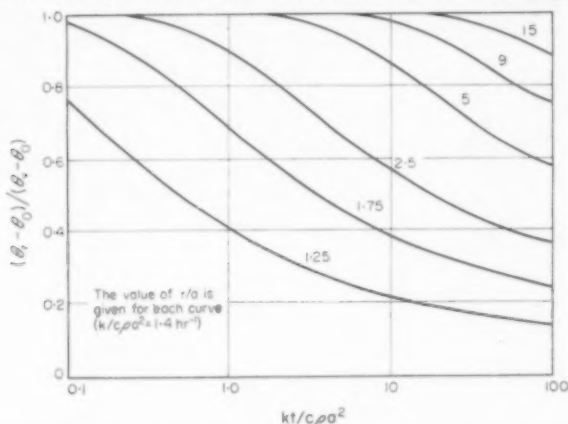
FIG. 9. Temperature–time distribution in the strata surrounding a cylindrical airway.

with time at a particular point in the strata. Curves similar to those in Figs. 8 and 9 are now available for circular roads through homogeneous strata for the following ranges of the dimensionless parameters involved: r/a from 1 to 30, k/ah from 0·2 to 2 and $kt/c\rho a^2$ from zero to 50; it is thus possible to calculate the heat flow, surface temperature and temperature distribution for strata under these conditions. Work is now in progress with the model to determine the effects, if any, on the curves caused by changes in the variables listed earlier.

(3) *The rise in air temperature along dry roadways*

The cylindrical theory of strata heat flow has been developed by HEERDEN (1951), on the three assumptions that there is negligible flow of heat in the strata parallel to the axis of the airway, that the thermal conductivity of the strata is independent of direction and that there is no effect within the strata or the air due to moisture. From HEERDEN's published data it is possible to make further calculations and so form some general conclusions concerning the features of an airway which are required to minimize the rise in temperature of roadway airflow.

Figure 10 gives values of the ratio $(\theta_v - \theta_x)/(\theta_v - \theta_o)$ at different distances along an airway after 10 days of cooling under five different conditions. The temperature at distance x is represented by θ_x. The most desirable conditions are obtained if the temperature rise along the airway is as small as possible which, on Fig. 10, means that $(\theta_v - \theta_x)/(\theta_v - \theta_o)$ should approach unity, for then θ_x approaches θ_0, the temperature of the air at the entrance where $x = 0$. A comparison of graph 1 in Fig. 10 with graph 2 shows the effect of a change in strata conductivity, and graphs 2 and

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3 illustrate the effect of a change in the heat transfer coefficient caused, not by a change in the airflow, but, say, by a different roughness of the strata surface. The improvement due to the lower coefficient is less than that achieved by changing the conductivity, and if graphs similar to 2 and 3 be drawn for times greater than 10
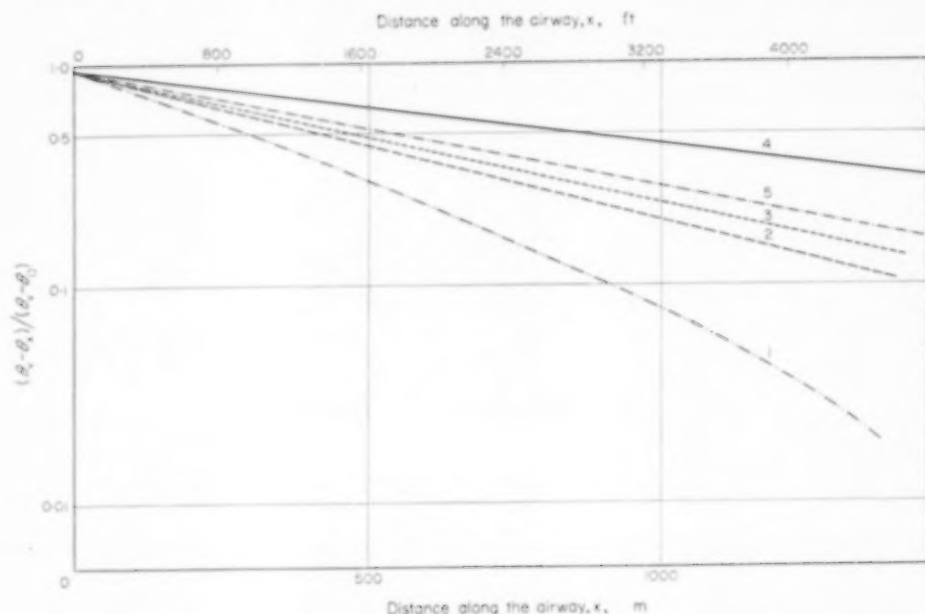
FIG. 10. The change in the temperature of air flowing along a new mine airway.
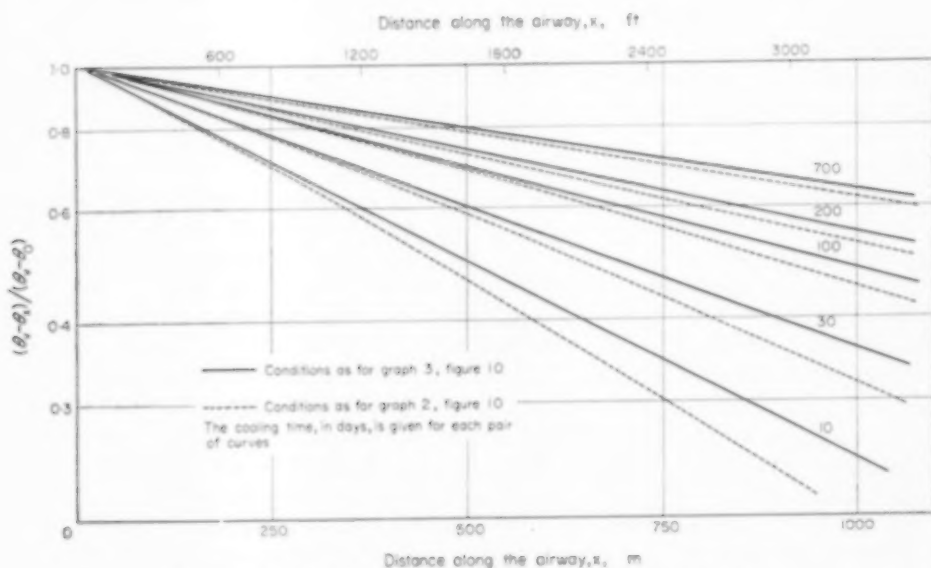
FIG. 11. The effect of the heat transfer coefficient during cooling.

days of cooling (Fig. 11) the benefit of a lower heat transfer coefficient becomes negligible after about 200 days of cooling.

It is not possible to increase the airflow in a roadway without, at the same time, increasing the heat transfer coefficient. Graphs 1 and 4 in Fig. 10 show the effect of such an increase, the higher airflow giving the more acceptable conditions. Again, it is not possible to change the roadway size for a given airflow without also changing the heat transfer coefficient. Graphs 4 and 5 show that increasing the size of a roadway for a given airflow is detrimental. From Fig. 10 it can therefore be concluded that a given airflow should be passed along as small a road as practicable, and that the surrounding strata should have as low a conductivity as possible. Both the intake air temperature and the virgin strata temperature should, of course, be kept to minimum values. The heat transfer coefficient should also be minimized and, for a given airflow in a roadway of minimum size, this is achieved by having the smoothest surface to the roadway. A thermal insulation on the roadway surface would also reduce the coefficient, but the cost of this could well outweigh the relatively short term value of the insulation.

Figure 10 can be used to estimate the change in temperature along a roadway at various times of cooling. Using the conditions for graph 4, as these are the most desirable, Fig. 12 has been obtained to show the rise in air temperature along a
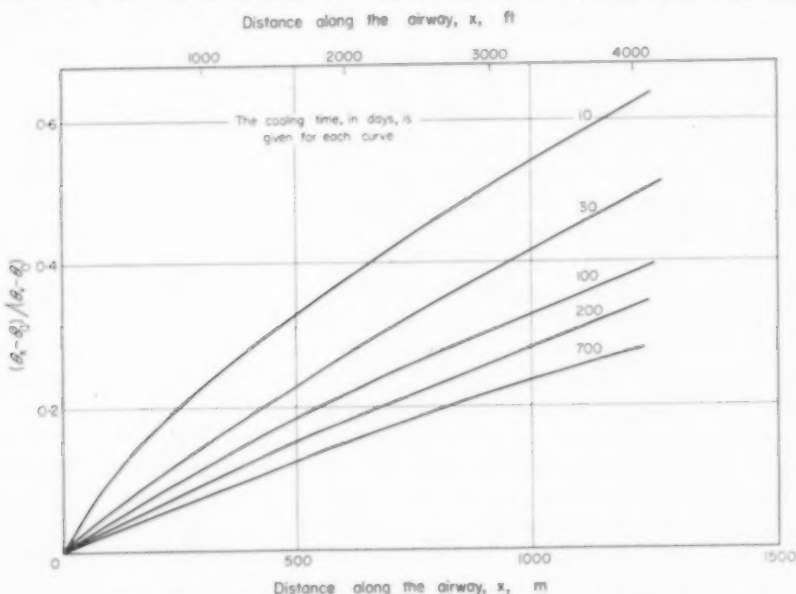
FIG. 12. Rise in air temperature along a typical mine airway.

good, newly ventilated secondary road. Such a road, if 920 m (1000 yd) long and subject to a value of 20 °C (36 °F) for $(\theta_v - \theta_o)$, a likely maximum value, would have an air temperature at the inbye end 10 °C (18 °F) above the intake air temperature after 10 days cooling, 8 °C (14 °F) above after 30 days and 4 °C (8 °F) after 700 days. At 700 days there is an overall temperature gradient of about 0·5 °C/100 m of road (0·8 °F/100 yd) which is very similar to the summer dry bulb temperature gradients for the secondary road in Fig. 3.

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In the special case of a shaft the cross-sectional area is circular, but the virgin temperature increases with depth and not in a linear manner (Fig. 5). It can be expected that there will be an upward heat flow in the strata parallel to the axis of the shaft in addition to the flow normal to the axis into the downcast air. The effect of this parallel heat flow could also be studied with the scale model technique using a model specially built to study the temperature gradient of the air along the axis of the shaft, making observations of the temperature distribution in the strata at right angles and parallel to the shaft axis.

(4) *The effect of moisture on mine air temperatures*

In every part of a mine airway the presence of moisture can have an effect on the wet bulb temperature, and in certain parts moisture evaporation may well be the most discomforting factor. Figure 3 indicates that in the shaft the drier air of winter gathers more moisture than the summer air. The pickup of moisture is also greater in the secondary roads than in the main roads, but by far the greatest rate of increase is along the face. Although the actual increase in moisture is of importance to the working miner, the rate of increase is a good guide to the presence of sources of moisture. It may well be that a very large part of the moisture gathered by a mine airflow comes from man-made sources, such as sprays, transported wet material and wet drilling techniques, and that very little moisture comes from the strata. In British coal mines opinion is undecided on which is the major contributory factor.

The effect on the thermal properties of rocks caused by saturating them with water is indicated in Fig. 4, and in the extreme cases the increases in thermal conductivity and diffusivity are not greater than 50 and 100 per cent respectively. Figure 10 indicates that an increase of 100 per cent in the conductivity would alter the temperature ratio $(\theta_v - \theta_x)/(\theta_v - \theta_o)$ by only a small amount. Taking the greatest likely value for $(\theta_v - \theta_o)$ as 20 °C (36 °F) the value of θ_x would be affected by no more than 2 °C (4 °F). It is difficult to see why rocks surrounding a mine airway should not always be saturated especially in deep mine airways subjected to high hydrostatic heads of water. Any change in conductivity or diffusivity of the order mentioned above is most unlikely to occur during the cooling history of a mine airway, if the moisture evaporated from the boundary surface is replaced by a flow of moisture through the strata. If the flow is only one of small magnitude compared to the normal moisture pickup by mine air, then it will convey negligible sensible heat into the airflow. Of much greater importance are the facts that an airway passes through a variety of rocks of quite different thermal properties, and that the thermal properties at a particular cross-section are by no means uniform in all directions. For these reasons it may be sufficient to regard a mine airflow as being surrounded by strata whose thermal properties remain comparatively unaffected by the passage of moisture through them. However, the evaporation of that moisture at the surface will have an important effect on the boundary conditions there. It will lower the strata surface temperature a few degrees, and this in turn will increase the temperature gradient in the strata and thus increase the strata heat flow. It is therefore necessary to know what the mass of moisture will be and what are the factors affecting it. References to standard works by JAKOB (1950) or ECKERT (1950) show that moisture mass transfer depends on the velocity of the airstream,

on the difference in the vapour pressure of the airstream and that due to air satur-
ated at the temperature of the strata surface, on the rubbing area of the strata air
boundary and, of course, the availability of water for evaporation. There may be
a significant difference between roadways that are smooth and fully lined, say,
with concrete blocks, and those roadways where the rough natural rock surface
is left open, the variability in the mass transfer coefficient being closely correlated
with that of the heat transfer coefficient. It is unlikely that one type of saturated
rock will be very different from another type if the permeabilities of both are
similar.

Some of the results from recent surveys of moisture pickup in British coal
mines are worth examining at this stage, but they cannot be regarded as con-
clusive, because the surveys were carried out for a limited time in a very limited
area and with an objective and an accuracy different from that required in the
special problem of moisture evaporation. Figure 13 shows the gain in enthalpy of
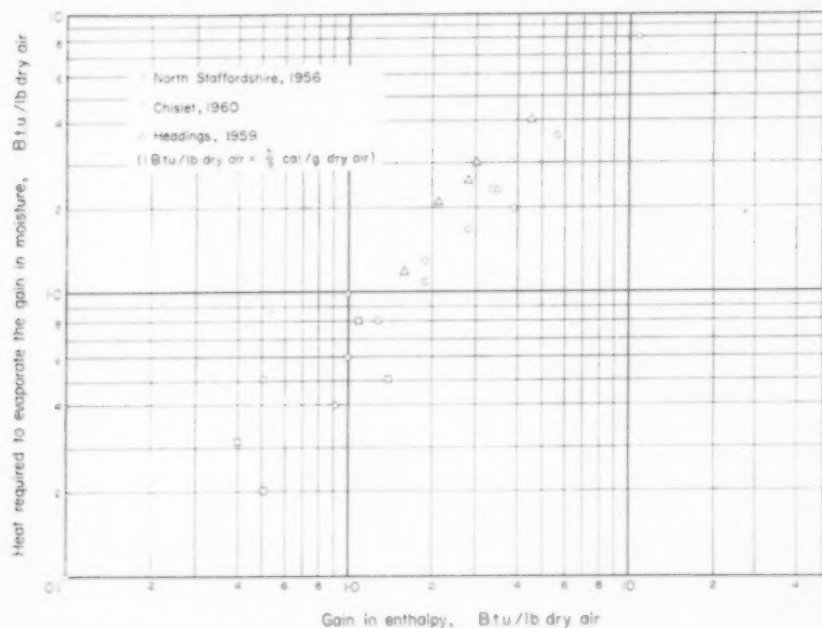
Fig. 13. Underground surveys of the heat required for evaporation of moisture.

an airflow passing along a length of mine airway or, in the case of headings, be-
tween the discharge end of a forcing duct system and a position very near the
end of the duct in the return airflow, plotted against the heat required to evaporate
the gain in moisture. Results are given from measurements in headings taken
during 1959, in level, main and secondary roads in the more comprehensive North
Staffordshire survey in 1956 and in main airways in Chislet Colliery in 1960. In
all the measurements there is always a gain in enthalpy and a pickup of moisture.
If the heat of vaporization had been taken entirely from the air itself there should
have been little increase in the enthalpy. This was never the case. In fact, as Fig. 13
shows, not only did the heat of vaporization come from a source other than the

air, but more heat than was required for vaporization was also acquired. How much of this heat and moisture came from man-made sources it is not possible to say with these results, except in the case of the Chislet figures where the heat and moisture pick-up came entirely from the surrounding strata. At Chislet the gains in moisture and heat were small compared to the gains in headings, as Fig. 13 indicates, but they were comparable with the lower valued gains in North Stafford-shire. The higher values in North Staffordshire, being more akin to the values in headings, would seem to underline the opinion, quoted earlier, that machine heat, wet drilling and water sprays constitute a very large part of the heat and humidity problem. Needless to say, this somewhat conjectural discussion of the moisture problem needs very careful study which should begin with a careful examination of the sources of moisture.

COAL FACE AIR TEMPERATURES

At the coal face fresh strata surface is continually being exposed at or near the virgin strata temperature. There are regions of quite low air velocity which are not helpful in the reduction of effective temperature, and there are areas of relatively intensive heat, such as machines, and high moisture, such as water infusion and sprays. Radiant heat and high humidity may also arise from coal that is likely to oxidize, as has been observed recently at Coventry Colliery. Factors such as these contribute to a rapid rise in the effective temperature along the face, such as is shown in Fig. 3, a rate of change which is usually greater than anywhere else in the pit.

(1) *Basic principles for limiting the rise in temperature along the face*

The coal face is unique in that every factor which can influence the effective temperature is particularly variable. The air velocity changes by an order of two to one when the coal is filled off, the use of machines and sprays is not continuous and the strata surface temperatures vary not only with depth of cover but also with time, especially when fine oxidizable coal is left loose on the surfaces. Such vari-ability, because of its order and uncontrollable nature, makes it very difficult to attempt to predict the changes in temperature along the face. It is therefore desir-able, in the first instance, to provide air of such a quality at the intake end of the face that it gives satisfactory conditions all along the face. Nevertheless, much can be done to limit the rise in temperature along the face. For example, the use of moisture for any purpose should be no more than the limit which is really required for the purpose. For the minimum dust concentration and lowest effective tem-peratures the air velocity should be within the range 60–120 m/min (200–400 ft/min). Outside this range there is an increase in the concentration of suspended dust. Below the range there is an undesirable increase in the effective temperature and already the upper value in the range is difficult to achieve. Undesirable sources of heat, such as oxidizable coal debris, should be avoided and machines should not be overpowered or abused.

(2) *Additional means of limiting temperatures at the face*

Even with all the above methods proving effective the rise in temperature along the face may still be excessive. Resource has then to be made, as suggested

by BROMILOW (1956), to a limitation of the working length of a face or the intro-
duction of air conditioning plant to supply cooled air to strategic points along the
face, possibly even supplying each man with a cooling unit.

If a man is enclosed in an air-ventilated suit, now well known in aircraft,
only a very small quantity of air, some 0.4 m³/min (14 ft³/min) is necessary for
his comfort. The air need not be chilled, but it should be dry with a water content
not more than 15 g/m³ (0.001 lb/ft³) so that evaporation of sweat can take place.
With a suit each man can be given quite a comfortable enclosure in almost any
environment with no more expenditure than is required to pipe a low quantity
of dry air to strategic points along the face. The main weakness of this system
underground is the need for each man to disconnect his air supply when moving
from one place to another.

There are other methods which could prove effective such as the transport of
material in the return airways to minimize the dust, heat and moisture pick-up by
air on its way to the face. MAERCKS (1957) has shown that the use of descensional
ventilation on an inclined face gives several climatic advantages, among them
being a lowering of the dry bulb temperature and humidity, although his findings
are at variance with those of BREUER et al. (1959).

SPECIAL ASPECTS OF THE PROBLEM

(1) *Some good ventilation practices for limiting the working temperature*

Sufficient has already been said about the importance of moisture pick-up and
the need to limit the use of water in the various operations where it is required.
There are also several man-made sources of heat. The compressed air line supplying
air to underground machinery is best taken underground in the upcast shaft so
that the heat of compression can be dissipated into the upcast air. Any inbye
compressors that are required underground, such as for pneumatic stowing in-
stallations, should be placed so that the heat is again dispersed into the return
airflow. As previously mentioned, coal that tends to oxidize and, in fact, all coal
mined from hot deep strata, should be conveyed in the return roadways so that
its heat and moisture can pass into the return air. In certain circumstances it may
be advisable to cover the system of conveying so that heat transfer and moisture
evaporation, even into the return airflow, can be minimized. Where it is possible,
electrical conveyor belt motors and their associated transformers should be placed
at the outbye end of a coal face. All the energy supplied to machinery used on
the face, unless any part of it raises material to a different height, will appear
somewhere as heat. It is therefore advisable to use only efficient machines and, if
necessary, to use them for limited periods of time if continuous use results in un-
acceptable rises in temperature of the surrounding airflow.

(2) *The special problem of continuous mining machines in headings*

A very serious problem in connection with machinery occurs with continuous
mining machines in the development of headings. A good example is the use of a
continuous tunnelling machine to drive headings up to 550 cm (18 ft) in diameter
to quite great distances in rock strata. To achieve a rate of advance that is suffici-
ently high for such a machine to compete economically with the more conventional
methods of tunnelling, now reaching 100 m (110 yd) a week, considerable power

will be required. Data recently published by ALLEN (1959) on tunnelling machines capable of giving these rates of advance in smaller tunnels, show that some 56 kW is required for a tunnel of diameter 100 cm (40 in.) and 150 kW for a tunnel of diameter 370 cm (12 ft). Scaling up these figures, on an area basis, for a tunnel of 550 cm (18 ft) a power of about 1000 kW is obtained, which will appear as heat, and the ventilating air will rise to very high temperatures. For example, if an airflow of 400 m³/min (14 000 ft³/min) absorbs even one half of this power as heat at or near the face of the heading, its temperature there will rise by 60 °C (107 °F), creating an impossible working condition. In order to ameliorate such conditions the basic principle should be to transfer the heat into water and convey it from the working face using this medium. In this way the heat transfer to the intake ventilating duct system is minimized. It may be possible to spray water directly on to the hot cutters and wash away the cut debris, the dust and the heat by a hydraulic conveying system, or alternatively, if the cutters are air cooled the airflow should be exhausted through a dust filter and a cooler so that the heat is extracted and again conveyed from the heading in water. The intake duct should be of large diameter, 1 m (3 ft) and thermally insulated. In extreme cases the delivered airflow may require refrigeration.

CONCLUSION

(1) For the efficient development of the deeper British coal seams three basic questions require answers:

(a) What will be the dry and wet bulb temperatures where the men will work?

(b) How will the conditions affect man's output of work?

(c) What amelioration, if any, will be required, and at what cost, to make the environment acceptable?

(2) As a new deep mine is opened up and developed the first and third questions are conveniently studied under the following headings:

(a) The thermal properties of the strata, including the virgin strata temperatures and their variation with depth.

(b) The effective temperature at the working face of a heading and the distance to which a heading can go before reaching the limiting temperature.

(c) The most effective ventilation system for a heading and, if necessary, the provision of air conditioning plant.

(d) The cooling of strata surrounding fully ventilated shafts and roadways.

(e) The rise in the dry and wet bulb temperatures of mine airflow on its way to the coal face.

(3) The second basic question requires further study before it can be answered adequately. Meanwhile, it is necessary to adopt some standard whereby mine air temperature can be judged. In the light of present knowledge it seems reasonable to take the limit of effective temperature within the range 27–29 °C (80–85 °F). It is also necessary to relate any limiting effective temperature to a dry bulb temperature appropriate to the humidity and air velocity that occur. A graphical method of doing this is shown in the paper.

(4) Use can be made of the survey boreholes, drilled to locate the coal seams, to obtain samples of the strata for the determination of their thermal properties and to obtain the virgin strata temperature. Virgin strata temperature can also

be determined from measurements of temperature in an advancing coal face in an existing nearby mine. The geothermic gradient in North Staffordshire has been shown to change considerably with depth, falling, numerically, to as low as 24 m/°C (44 ft/°F), due to the low thermal conductivity of the coal measure strata.

(5) A deep heading is best ventilated by a leakless forcing duct system for the air reaches the face with a minimum pick-up of moisture and the lowest temperatures are obtained by thermally insulating the duct. A technique has been developed whereby the discharge air temperature in a forcing system can be calculated as the heading advances. The more complex problems that arise when the duct leaks and when strata cooling is treated more exactly has been solved on an I.B.M. 650 computer, and the solutions are now being checked with measurements in advancing headings.

(6) In long, deep headings, even with thermally insulated ducts of large diameter carrying a large airflow, discharge air temperatures in excess of 24 °C (75 °F) can be expected. Further amelioration can be obtained by using a refrigerator at the duct discharge. The heat is removed from the heading by circulating the condenser water between the refrigerator and a water-to-air heat exchanger placed in the airstream of a main roadway.

(7) Recent work supports the contention that a mine roadway in cross-measure strata can be represented theoretically by a hollow circular cylinder surrounded by a medium of uniform thermal properties. To ensure that the mathematical function involved is truly representative for the full range of all the variables and also to produce graphs of the function for practical use, a laboratory scale model technique has been devised for the evaluation of the temperature distribution and strata heat flow. This technique has many advantages, the most important being that phenomena taking many years underground can be examined in the laboratory in a few hours.

(8) Theoretical considerations indicate that the rise in temperature of air flowing along a roadway is kept to a minimum if:
(a) the roadway is driven through strata with the lowest thermal conductivity and virgin strata temperature;
(b) a given airflow is passed along as small a road as practicable;
(c) the heat transfer coefficient at the boundary is kept low, say, by having a smooth strata surface.
Thermal insulation on the roadway surface would also reduce the coefficient but after about 200 days of cooling the boundary thermal resistance becomes small compared to the increase in the strata resistance as it is more extensively cooled.

(9) Theoretical estimates of air temperature indicate that intake air at 20 °C (36 °F) below virgin strata temperature after travelling along a dry roadway of 920 m (1000 yd) in length would rise 10 °C (18 °F) after 10 days cooling and 4 °C (8 °F) after 700 days.

(10) Measurements of moisture movement through the strata have indicated that the flow may be small enough not to alter the strata thermal properties. A more important factor affecting the thermal properties is caused by the non-homogeneous nature of the strata at any cross-section. Because of these features

a mine airway must be regarded as being surrounded by strata whose thermal properties have values which are uniform in all directions but which, nevertheless, need to be determined.

(11) Preliminary studies of moisture pick-up in British coal mines indicate that not only does the heat of vaporization come from a source other than the air, but more heat than is required for vaporization is also acquired by the airflow. The rate of evaporation of moisture into mine air increases towards the coal face indicating that the underground sources of moisture may be largely manmade and that possibly very little moisture comes from the strata.

(12) The maximum rate of rise in effective temperature occurs at the coal face. Any prediction of the rate, being subject to considerable variability of the factors on which it depends, is unreliable and it is therefore best to supply air to the face of such a quality that it gives satisfactory conditions along the whole face. To obtain a low effective temperature and minimum dust concentration the use of water should be confined to the value required for the purpose, air velocity should be within the range 60–120 m/min (200–400 ft/min), machines should not be overpowered or abused, and fine, oxidizable coal should be cleaned up.

(13) Further amelioration of the conditions on the coal face can be obtained by (a) the limitation of the working length of the face, (b) the introduction of air conditioning plant to distribute cool air to strategic points along the face, (c) the use of air-ventilated suits using very small quantities of dry air and (d) the transport of hot, moist material in the return airways.

(14) From the climatic point of view good ventilation practice includes (a) installation of compressed air lines in the upcast shaft, (b) the positioning of inbye compressors so that their heat is dispersed into the return airflow, (c) the conveyance of oxidizable coal or warm coal from great depth in the return airflow, if necessary enclosing the material to prevent loss of heat and moisture, (d) installation of electrical conveyor motors and their associated transformers at the return end of a face and (e) the use of efficient machines on the face, if necessary using them for limited periods of time.

(15) There is a special problem of obtaining acceptable working temperatures at or near the face of a continuous machine-mined heading, where the rate of advance and size of tunnel are so large as to require powers up to 1000 kW. The basic principle to any solution of this problem should be to transfer the the heat into water and convey it out of the heading in this medium. Water cooling of the cutters makes possible a hydraulic system for the conveyance of heat, dust and debris from the heading by piped water. If air cooling of the cutters is used, then the air must be cooled before it is exhausted from the heading, and the heat and dust extracted from it carried away from the heading by water. The intake airflow can be supplied through a large duct which is thermally insulated.

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GRANULOMÉTRIE PHOTOÉLECTRIQUE DES BROUILLARDS

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Abstract—A rapid method is described for finding the sizes of drops between 4 and 100 μ diameter, such as occur in fogs and mists; it is based upon photoelectric measurement of the light scattered by individual drops and has the advantage of allowing them to remain freely suspended in air during the observations.

SOMMAIRE

On expose une méthode permettant de connaître rapidement les dimensions des gouttes qui composent un brouillard naturel ou artificiel, ainsi que leur répartition; et à cet effet, on procède à une étude optique et photoélectrique individuelle des gouttelettes.

Puis on présente un appareil basé sur l'étude ci-dessus et dont le double intérêt réside dans la rapidité d'obtention des résultats, ainsi que dans le fait qu'il permet l'observation des gouttes d'eau sans modifier leur état puisqu'elles restent libres en suspension dans l'air pendant toute la durée de la granulométrie.

I. ÉTUDE PRÉLIMINAIRE

Au cours d'une étude préliminaire, effectuée en collaboration avec Bricard *et al.* (1959), nous avons indiqué le principe d'une méthode optique et photoélectrique, permettant le dénombrement et la mesure de gouttelettes d'eau dont le diamètre était compris entre 10 μ et 100 μ. La source S utilisée était une lampe Philips SP1000 à refroidissement par eau. Par la suite, nous l'avons remplacée par une HBO 200 ($2,5 \times 1,3$ mm) de luminance moyenne 25,000 stilbs, alimentée en courant continu par un redresseur dont la modulation résiduelle en tension est inférieure à 3 pour cent de la composante continue et dont l'alimentation est elle-même stabilisée. Le montage optique (Fig. 1), légèrement modifié, comporte une lentille plan-parabolique L' qui forme l'image de S sur la première lentille L' d'un condenseur d'ouverture 64° corrigé des aberrations chromatiques et de sphéricité. Ce condenseur forme l'image I d'un diaphragme rectangulaire D vertical placé derrière L. Une lentille divergente $\mathscr{L}$ placée devant le condenseur permet de réduire la distance SI. Grâce à ce montage optique étudié par C. Véret, l'image I est éclairée de manière approximativement uniforme.

Cette image I est située au centre du champ du microscope d'observation dont l'axe est perpendiculaire à la direction SI. Les gouttes libres en suspension dans l'air sont aspirées par un ventilateur, de manière à ce qu'elles traversent l'image I

suivant une direction à 45° de *SI*, dans le plan déterminé par *SI* et l'axe du micro-
scope. La lumière diffusée à 90° par chaque gouttelette qui traverse *I*, d'abord
reçue par le microscope, est envoyée sur un photomultiplicateur 51 AVP, à l'aide
d'un dispositif optique qui conjugue la pupille de l'objectif du microscope avec la
photocathode (FIG. 1). Ce système classique permet d'éclairer uniformément la
totalité de la surface utile de la photocathode quelle que soit la position de la
goutte dans le champ du microscope. La lentille $\mathscr{L}'$ sert uniquement à diminuer
la distance objectif-photocathode. Afin de réduire l'encombrement, le photomulti-
plicateur est situé au-dessus du microscope, d'où la nécessité des deux miroirs
M et *M'*. Initialement, un milliampèremètre permettait de mesurer le courant
anodique; par la suite nous l'avons supprimé et nous avons repris le signal obtenu
à la sortie du photomultiplicateur par un oscilloscope dont on photographie
l'écran.
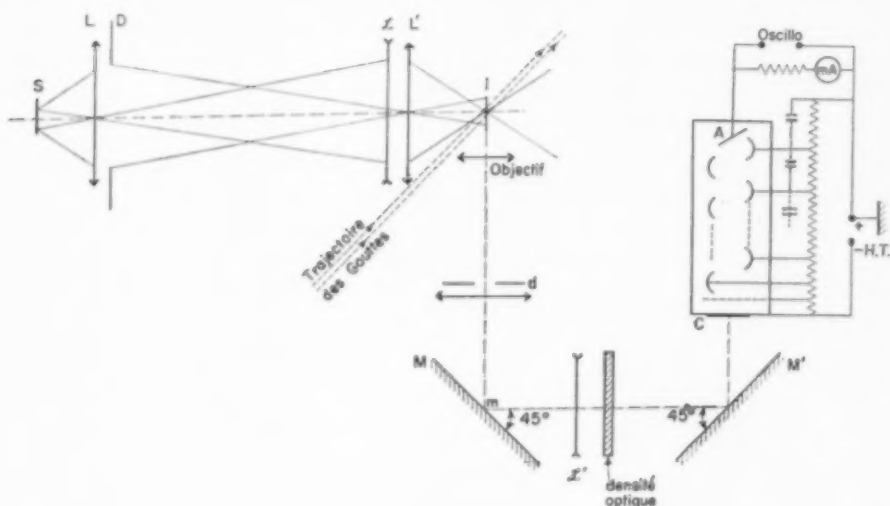
FIG. 1

ÉTUDE D'UNE GOUTTE D'EAU IMMOBILE DANS LE CHAMP DE L'APPAREIL

(*a*) *Généralités.* Une gouttelette d'eau stabilisée par de la glycérine et immobi-
lisée par un fil d'araignée (DESSENS, 1946) dans le champ de l'appareil, est observée
perpendiculairement à l'axe du faisceau convergent qui l'éclaire; elle présente trois
images correspondant à la lumière réfléchie à la surface extérieure, transmise par
la goutte après deux réfractions successives et transmise après deux réflexions
internes (BRICARD et DELONCLE, 1959).

Pour connaître le flux diffusé par une gouttelette isolée fixée sur fil d'araignée,
il suffit de soustraire, du flux total reçu, le flux diffusé par le fil dépourvu de goutte-
lette.

On a déterminé l'étendue du champ dans laquelle on peut admettre que le
flux diffusé par une goutte donnée est constant α 5 pour cent près, quelle que soit la
position de cette goutte dans le champ.

On a trouvé les valeurs suivantes:

460 μ suivant la direction de la lumière incidente
250 μ suivant l'axe du microscope
810 μ suivant la direction perpendiculaire aux deux précédentes.

Pour procéder à cette étude de l'image I, on déplace dans le champ de l'appareil une gouttelette d'eau dont la position est parfaitement bien déterminée.

La détermination suivant l'axe du microscope s'effectue en projetant l'image que donne de la goutte un second microscope dont l'axe optique est orienté suivant SI; si l'oculaire de ce second microscope comporte un micromètre, il est facile de repérer la position de la goutte dans le champ.

La partie utilisable de l'image I est parfaitement définie d'une part par un diaphragme d convenablement placé dans le microscope, d'autre part par la profondeur de champ du microscope.

Pour travailler toujours dans les mêmes conditions, c'est-à-dire pour avoir des résultats reproductibles, on dispose d'un diffuseur-type (petit fil métallique monté sur raquette, que l'on peut à volonté amener dans le champ, et qui donne un signal connu et pris pour référence).

(b) *Calcul du flux F reçu par la photocathode du photomultiplicateur lorsqu'une goutte de diamètre* $d\mu$ *donné traverse le champ (ou s'y trouve immobilisée)*

D'après les résultats de Wiener basés sur l'application des lois de la réflexion et de la réfraction, il est possible de calculer l'intensité totale diffusée par la goutte dans la direction faisant l'angle α avec la direction de la lumière incidente (BRICARD et DELONCLE, 1959); elle est proportionnelle à l'intégrale:

$$I(\alpha) = \int_0^U \int_0^{2\pi} f(\theta) . \sin \alpha . d\alpha . d\varphi \tag{1}$$

$f(\theta)$ est la fonction de diffusion de Wiener; θ est défini par:

$$\cos \theta = \cos \alpha . \cos \alpha' + \sin \alpha . \sin \alpha' . \cos \varphi$$

U représente l'ouverture du condenseur = 64°.
Le flux que recoit l'objectif du microscope est proportionnel à:

$$I = 2\pi \int_{-u/2}^{+u/2} I(\alpha) . \sin u . du \tag{2}$$

u étant l'ouverture de l'objectif = 24°.
Connaissant les valeurs $I_1 = 2\pi.0,832$ à 90° et $I_2 = 2\pi.68,2$ à 0° de l'intégrale calculées au cours d'un précédent travail (BRICARD *et al.*, 1959), et étant donné les conditions expérimentales exposées précédemment (lampe HBO 200, $U = 64°$, $u = 24°$, P.M.51 AVP), nous avons trouvé (DELONCLE, 1960b) que le flux F reéu par la photocathode du photomultiplicateur lorsqu'une goutte de diamètre d_μ traverse le champ, est donné par:

$$F = 0,098 . 10^{-6} . d^2 \text{ lumens} \tag{3}$$

où d est exprimé en μ.
À ce flux F correspond un signal S recueilli à l'oscilloscope:

$$S = 59 . d^2 \text{ mV}. \tag{4}$$

Ainsi, une goutte de diamètre $d = 9\,\mu$ donne un signal théorique de 4780 mV. L'expérience montre qu'une goutte de $9\,\mu$ donne un signal de 5500 mV. Étant donné l'approximation faite sur la valeur du rendement du P.M., l'accord des résultats paraît satisfaisant; on voit cependant que le flux diffusé à 90 ° de la direction du faisceau incident est légèrement supérieur à celui que prévoit la théorie. Ceci confirme un résultat expérimental déjà signalé (BRICARD, 1943).

(c) *Variations de l'intensité lumineuse diffusée par une goutte en fonction d'inclinaison de la direction d'observation sur l'axe du faisceau incident*

La figure 2 représente les variations due courant anodique en fonction de l'angle α de la direction de l'axe du microscope avec la direction du faisceau incident, lorsqu'on observe avec l'appareil, une goutte de rayon déterminé (courbe en trait plein). Ceci donne en valeurs relatives les variations de l'intensité diffusée par la goutte en fonction de l'angle α. D'autre part, nous pouvons calculer ces variations à partir de l'expression '2' (courbe en pointillé). Ces courbes, expérimentale et théorique, n'étant valables qu'en valeurs relatives, ont été raccordées pour la valeur $\alpha = 50°$. On constate un bon accord entre les résultats du calcul et ceux des mesures, bien que le flux diffusé au voisinage de la direction perpendiculaire à celle de la lumière incidente soit légèrement supérieur à celui que prévoit la théorie; ceci est en accord avec les résultats obtenus au paragraphe précédent.
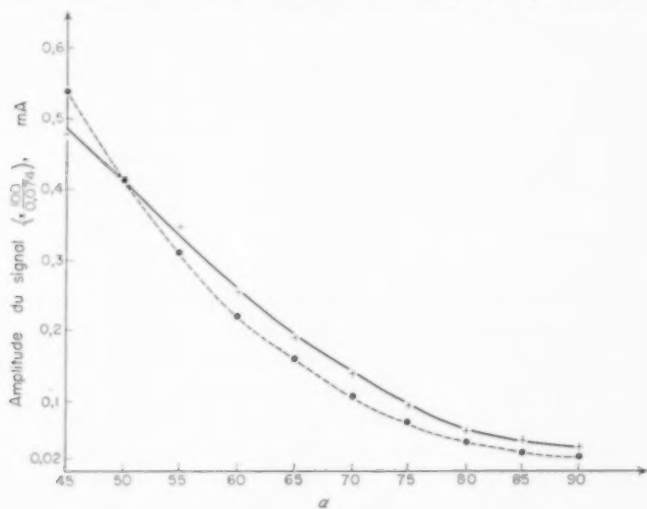
FIG. 2

(d) *Variations de l'intensité lumineuse diffusée par une goutte en fonction de ses dimensions*

On se place dans le cas où *Im* est perpendiculaire à *SI*, c'est-à-dire à 90 ° de la lumière incidente, et on opère avec des gouttes dont le diamètre est compris entre $6\,\mu$ et $96\,\mu$. Ces gouttes de différentes dimensions sont recueillies sur le fil d'araignée exposé à la pulvérisation d'un nébuliseur médicamenteux. On fait défiler ce fil dans le champ du microscope, au centre de l'image *I*, en le diploçant dans le sens de sa longueur. On peut alors soit mesurer le courant anodique, soit lire sur l'oscilloscope le signal *S* mV correspondant au flux lumineux diffusé par les gouttes.

Ensuite, tout l'ensemble du système miroirs—P.M. est remplacé par un objectif ($\times 60$) et par un oculaire ($\times 17$) muni d'un micromètre, ce qui permet de mesurer le diamètre d_μ des gouttes.

La courbe 3 représente les variations du signal mesuré, c'est-à-dire du flux diffusé en fonction des dimensions des gouttes (courbe en trait plein). Sur la même figure, on a représenté les mêmes variations calculées en admettant que le flux diffusé est proportionnel au carré du rayon de la goutte, en se raccordant pour un diamètre de 96 μ. On voit que les deux courbes sont concordantes (BRICARD et al., 1959).
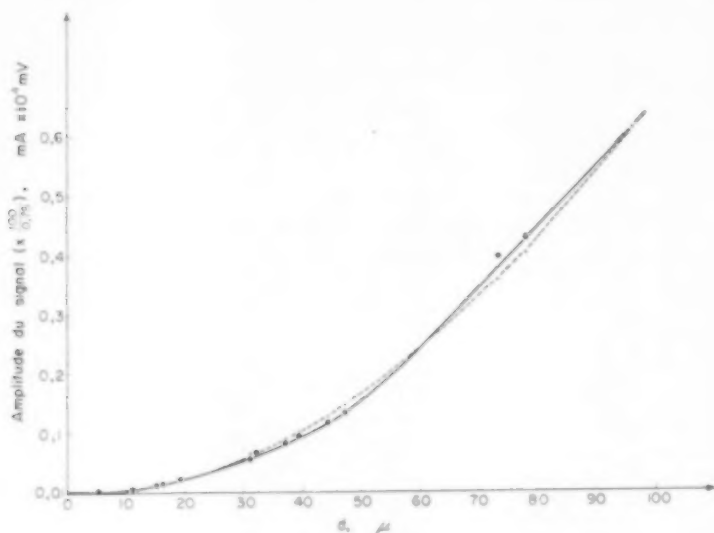
FIG. 3

Les mesures, en accord avec l'expression[3], montrent que pour $\alpha = 2\pi r/\lambda = 100$ c'est-à-dire pour un diamètre d'environ 16 μ, le flux reçu par la photocathode est de $24,84.10^{-6}$ lumen. Mais si l'expression[3], basée sur les lois de l'optique géométrique, exprime simplement les propriétés des particules qui nous intéressent dans ce travail, il n'en est plus de même dans le cas où le diamètre des gouttes devient inférieur à 10 λ. La théorie de Wiener doit alors être abandonnée au profit de la théorie plus générale de Mie, dont les résultats ont été calculés par PENNDORF (1960). D'après ces résultats, l'intensité $i_1 + i_2$ diffusée à 90° par une particule non absorbante d'indice $n = 1,33$ est de l'ordre de 2.10^2 pour $\alpha = 100$ et de 9.10^{-3} pour $\alpha = 0,82$. Il est facile d'établir que le flux reçu par le P.M. lorsqu'une goutte de diamètre $d^\mu = 0^\mu,13$ (ce qui correspond à $\alpha = 0,82$) traverse le champ, est égal à :

$$F = 24,84 . 10^{-6} . \frac{9 . 10^{-3}}{2 . 10^2} = 11 . 10^{-10} \text{ lumen.}$$

Le flux minimum détectable à l'aide du 51 AVP convenablement monté étant d'environ 4.10^{-10} lumen, nous pensons que l'on peut espérer détecter des gouttes dont le diamètre minimum pourra atteindre $0^\mu,13$, et au moins pénétrer dans le domaine submicronique.

3. RÉALISATION

Le principe du montage de l'appareil (DELONCLE, 1960a) réalisé à partir des résultats précédents est le même que celui que nous avons décrit au paragraphe I. On dispose de plusieurs réglages; la lampe peut être déplacée dans trois directions (en hauteur, suivant la direction de la lumière incidente et suivant la direction perpendiculaire aux deux autres). Il est également possible de jouer sur la hauteur du condenseur et sur sa distance à la source.

(a) Réglage et étalonnage

Selon la méthode exposée au paragraphe 2.d, on trace la courbe d'étalonnage de l'appareil: $S_{mV} = f(d_\mu)$, (Fig. 3). Comme nous l'avons vu précédemment, le signal varie comme le carré du rayon de la goutte, du moins jusque $d = 6\,\mu$.

Le photomultiplicateur, alimenté sous 1560 V par une alimentation régulée H.T. stabilisée au 1/10,000, n'est linéaire que jusque environ 0,55 mA. Les gouttes dont le diamètre dépasse $9\,\mu$ envoient sur la photocathode un flux qui produit un signal supérieur. Pour pallier à cet inconvénient, deux solutions s'offraient: soit diminuer la tension d'alimentation du P.M., soit travailler avec un flux incident plus faible. Afin de faciliter le dépouillement des mesures (effectué sur les photos de l'écran de l'oscilloscope), il s'est avéré plus simple de sélectionner directement les gouttes par catégories, en plaçant différentes densités optiques devant la photo-cathode.

De plus, on s'est assuré que l'influence du bruit de fond sur les mesures était négligeable, et que dans la limite des vitesses de passage des gouttes dans le champ de l'appareil, les amplitudes mesurées sur l'oscilloscope correspondent bien aux maxima des signaux envoyés par les gouttes.

(b) Probabilité de passage des gouttes dans le champ de l'appareil

Il peut arriver que plusieurs gouttes se trouvent ensemble dans le champ. Elles sont alors enregistrées simultanément, donnant ainsi un seul signal, somme des signaux élémentaires et se comportent comme une goutte unique beaucoup plus grosse. Il est intéressant de calculer la probabilité avec laquelle cette éventualité peut se produire. Le calcul montre, étant donné les caractéristiques du champ de l'appareil, que la probabilité d'avoir simultanément deux gouttes dans le champ est 22 fois plus faible que celle d'en avoir une seule, et que celle d'en avoir trois est encore 32 fois plus faible que la précédente, pour un brouillard de densité 1000 gouttes/cm³.

(c) Coefficient de captation de l'appareil (correction de bords)

Une goutte peut être occultée partiellement par le diaphragme de champ et de ce fait, donner un signal plus faible qu'il ne serait normal, donc se comporter comme une goutte plus petite. Une correction est alors nécessaire, et peut être représentée par la relation:

$$\frac{C_i}{SN_i} = \frac{2d}{lN_i} \cdot \sum_{k=i+1}^{k=n} \left(\frac{N_k}{\sqrt{k}}\right) - \frac{2d}{l\sqrt{i}} \tag{5}$$

d représente le diamètre de la plus petite goutte contenue dans le brouillard, l la largeur du champ, S sa surface, n le nombre d'intervalles de la statistique des

gouttes, C_i la correction à apporter au nombre N_i de gouttes de l'intervalle i.

Dans le cas présent, étant donné les dimensions du diaphragme de champ et des gouttes mesurées, cette correction n'a pas dépassé 10 pour cent pour les plus petites gouttes. Pour établir cette relation, on a assimilé la section droite d'une goutte de diamètre d à un carré de côté d. Le calcul montre, en effet, que cette approximation ne change pas l'ordre de grandeur de la correction.

(d) Granulométrie

Cet appareil a été expérimenté dans la chambre à brouillard de Bellevue (DE LONCLE, 1960a). Tout l'appareillage baigne dans le brouillard. Ce brouillard est obtenu à l'aide d'un système de trois pulvérisateurs à air comprimé, placés à la partie supérieure d'une pièce d'environ 5 m de haut et de superficie 4×4 m². La densité du brouillard et la grosseur des gouttes peuvent être réglées en jouant sur la pression de l'air comprimé, sur le niveau de l'eau qui est aspirée par dépression, et aussi sur la position de l'aiguille mobile de l'ajutage de sortie des pulvérisateurs. Le niveau de l'eau doit être maintenu constant, ainsi que la pression de l'air comprimé si l'on désire une production homogène de gouttelettes.

En même temps que la granulométrie, on a fait des prélèvements à l'aide d'un cascade Impactor (MAY, 1960) muni de films Kodak au collargol (GODARD, 1959), de manière à pouvoir comparer les résultats. On voit qu'ils sont concordants. A titre d'exemple, la Fig. 4 comporte en trait plein, la courbe directement obtenue avec
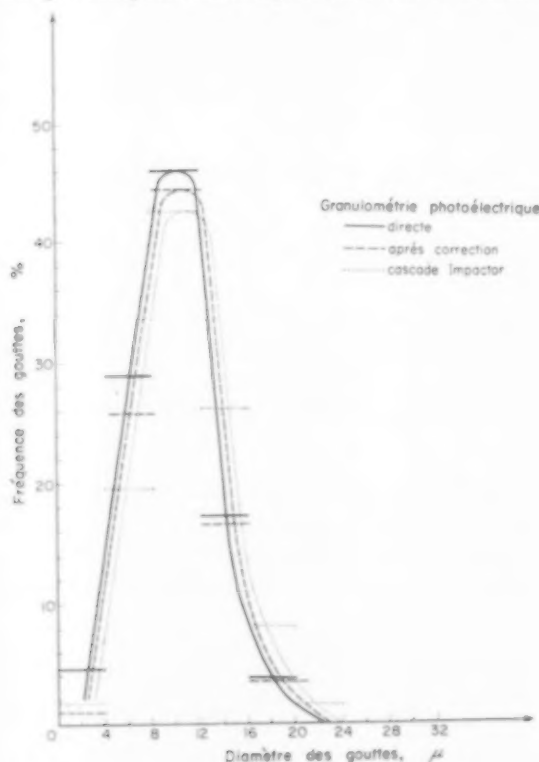
Fig. 4

Fig. 5

Fig. 6

notre appareil, en pointillé la même courbe après correction c'est-à-dire compte tenu du coefficient de captation de l'appareil, et enfin la courbe donnée par le Cascade Impactor.

La Figure 5 montre la photo de l'un des films porté par un plaque du Cascade Impactor; la Fig. 6 représente un aspect de l'écran de l'oscilloscope au cours de la granulométrie.

4. CONCLUSION

Convenablement étalonné l'appareil que nous présentons ici permet donc de caractériser rapidement un brouillard naturel ou artificiel, ou un aérosol. Et ceci simplement d'après le nombre et l'amplitude des impulsions photographiées sur l'écran de l'oscilloscope. Dans le cas présent, on détecte facilement les gouttes de $3\,\mu$, les plus petites que contenait notre brouillard et l'on espère, en poussant l'étalonnage, descendre au-dessous du μ.

On se propose maintenant d'équiper cet appareil, d'un sélecteur d'amplitudes et d'un système de comptage, afin d'obtenir des résultats plus rapides et de pouvoir suivre ainsi l'évolution d'un brouillard naturel.

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M

TOXIC FUMES FROM SHOTFIRING IN COAL MINES

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INTRODUCTION

THE object of this paper is to summarize the evidence on the probable effect of fumes produced by shotfiring on longwall coal faces and in tunnels and headings.

Following standard practice all concentrations of gases are given in terms of parts per million (p.p.m.) although there are some theoretical objections to this procedure. No attempt has been made to convert the concentrations given to terms of Normal Temperature and Pressure, as in many cases the necessary data are lacking.

I. THE PRODUCTS OF DETONATION OF EXPLOSIVES

The following writers have described the products of detonation:
GRAHAM and LAWRENCE (1948); GRAHAM and RUNNICLES (1943); LINGENBERG (1954); TOLCH and PERROTT (1929); VON OETTINGEN (1941); and WIRTH (1930). These products are:

(a) Finely divided solids of rock and coal.
(b) Unexploded particles of explosive.
(c) Liquid droplets of nitric and nitrous acids.
(d) Gases: (i) Carbon Dioxide; (ii) Nitrogen; (iii) Ammonia; (iv) Carbon Monoxide; (v) Hydrogen Sulphide; (vi) Oxides of Nitrogen.

Unexploded particles of nitroglycerine in concentrations of less than one-tenth of a part per million have been measured on the coal face (WOOD, 1957). LINGENBERG (1954) has detected ions of chlorine, sodium, calcium, carbonates and sulphates after explosion. These however are of small importance here.

Cyanides may be formed in the conditions of high temperature and pressure at the point of explosion, but there are no reports of their presence.

The manufacturers of explosives state that no hydrogen sulphide is produced. Tests on 60 per cent ammon-gelignite, a nitroglycerine explosive, showed no trace of the gas (JOHNSON *et al.*, 1940). Tests made recently in the collieries of one National Coal Board Area failed to disclose its presence, although many miners believe that it is possible to smell the gas underground after explosives are fired. It seems most unlikely that hydrogen sulphide is produced in significant amounts. The same appears to be true of ammonia (CORBETT and TIETZ, 1951; GRAHAM and LAWRENCE, 1948).

The main toxic factors, therefore, appear to be carbon monoxide and oxides of nitrogen: this paper deals mainly with the latter gases.

The oxides of nitrogen

There are eight oxides of nitrogen (SIDGWICK, 1950) but only a few of these are either likely to be present after explosion, or are of toxicological importance.

Nitrous oxide (N_2O) has not been reported present in shotfiring fumes and although in quantity it is productive of anaesthesia and abnormal behaviour (STEINBERG, 1956) the amounts likely to be present will not have any significance. The anhydride (NO_3) can be prepared only by special methods and is very unstable (OGG, 1953) while the sesqui-oxide (N_2O_3) is said to dissociate quickly into the dioxide (NO_2) and the monoxide (NO). Neither the sesqui-oxide nor the pentoxide (N_2O_5) have been reported in shotfiring fumes. DIGGLE and GAGE (1954) state that the pentoxide is of higher toxicity than NO_2, but there is some doubt about this (STOKINGER, 1957). It is unlikely to be present because it decomposes into the tetroxide (N_2O_4) and oxygen at temperatures above 0 °C (SIDGWICK, 1950). In the presence of ozone NO_2 is converted to N_2O_5 (DIGGLE and GAGE, 1954), but the amounts likely to be thus produced underground are negligible. The hexaoxide (N_2O_6) can be prepared by special methods only.

The remaining oxides are nitric oxide (NO), and nitrogen dioxide (NO_2) and its polymer (N_2O_4)—the tetroxide. These appear to be the most important ones and together constitute what are commonly known as "nitrous fumes"[*] or nitrogen oxides.

These oxides are heavier than air. Both are soluble in water, which may account for the presence of the acids in droplet form after the explosion. It is said (LEHMANN and HASEGAWA, 1912) that they can be detected by smell, but this is unlikely below ground. NO and NO_2 are colourless while N_2O_4 is characteristically brown in colour. It is very unlikely that any such brown fumes would be seen after shotfiring underground on account of the dust and smoke raised and the general low level of visibility.

Conversion of nitric monoxide to dioxide

Nitric monoxide, in the presence of oxygen, is converted into nitrogen dioxide. It was once thought that this reaction proceeded instantaneously but BODENSTEIN (1918) has shown that in low concentrations it takes place more slowly. There is some uncertainty over the actual speed of conversion. (ELKINS, 1946; SILVERMAN and HUSAIN (1951); SMITH, 1943; TODD, 1924; WADE et al., 1950.)

2. LEVELS OF CONCENTRATION MEASURED UNDERGROUND

Table 1 sets out information available on concentrations of oxides of nitrogen, and also carbon monoxide, measured below ground in relation to work-place, quantity of ventilation and amount of explosive fired. Results are taken from: PERROTT et al. (1930); HALDANE and GRAHAM (1935); GRAHAM and RUN-NICLES (1943); GRAHAM and LAWRENCE (1948); TIFFANY et al. (1950); WADE et al. (1950); FOWLER and STANTON (1955); and NATIONAL COAL BOARD SCIENTIFIC DEPARTMENT, DURHAM DIVISION (1955).

[*]It is customary to refer to NO_2 and N_2O_4 together as nitrogen dioxide or peroxide, and to NO as nitric oxide or monoxide: this practice has been followed.

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TABLE 1. CONCENTRATION OF NITROUS FUMES AND CARBON MONOXIDE MEASURED UNDERGROUND
DURING SHOTFIRING OPERATIONS

Work place	Weight of explosive (ounces)	Range of measure-ments of venti-lating air (ft³/min)	Time of sampling	Nitrous fume concentration recorded (p.p.m.)			Carbon monoxide concentration recorded (p.p.m.)		
				Maxi-mum	Mini-mum	Mean	Maxi-mum	Mini-mum	Mean
Coal face— main section	6–72	5000	During filling shift	75	5	25	90	16	40
	(not stated)	(not stated)	During filling shift	90	—	—	460	16	200
	4–8	(not stated)	5 min after firing	18	9	14	460	60	210
	2–10	up to 14,000	3 min after firing	56	5	20	—	—	—
Coal face— fast ends	6–72	(low)	At intervals in shift	172	< 10	140	700	29	600
	(not stated)	(low)	Up to 20 min after firing	200	—	—	—	—	—
Headings	8–160	Up to 1000	1 min after firing	150	10	48	—	—	—
	8–160	do.	5 min after firing	76	5	38	360	200	310
	160	do.	2 hr after firing	—	—	40	—	—	—
	Up to 24	do.	5 min after firing	56	17	—	—	—	280
	24–48	do.	5 min after firing	150	< 5	—	—	—	—
	48–72	do.	5 min after firing	172	20	—	360	—	—
Tunnels	1520	5300	1 min after firing	245	110	—	1060	530	—
	1520	5300	10 min after firing	45	12	—	500	240	—
	(not stated)	(not stated)	10 min after firing	201	97	—	—	—	—
Headings: abnormal ventilation conditions	48	(v. low)	2–5 min after firing	—	—	270–345	—	—	600–2400
	48	(v. low)	15 min after firing	—	—	118–150	—	—	600–2100
Tunnels: abnormal ventilation conditions	1850	(v. low)	10 min after firing	810	105	375	1080	30	530
	1850	(v. low)	20 min after firing	492	62	235	—	—	—
	1850	(v. low)	45 min after firing	223	52	105	—	—	—

As will be seen from the table the amount of carbon monoxide present is usually much greater than nitrous fumes. Laboratory tests show the proportion to be of the order of 6 : 1. Different makes of explosive produce different amounts, for the same weight fired, of both carbon monoxide and nitrous fumes. Laboratory tests of the explosives used in one Division show a range of 0·05 l. to 0·68 l. of NO_2 per 100 g of explosive and 0·58 l. to 3·3 l. of CO per 100 g. However, it is well known that laboratory tests give different results from field trials of explosives (SUVAROV, 1944); for example, tests on the same explosive in the laboratory gave 0·05 l. oxides of nitrogen and in the field 0·69 l. per 100 g. (GRAHAM and LAWRENCE, 1948). The converse has been observed with carbon monoxide (TIFFANY et al., 1950).

Except in a general way, as shown in the table, there is no close relation between the amount of fumes produced and the quantity of explosive fired. Neither overcharging nor undercharging has much effect on the volume of fumes produced (GRIMSHAW, 1948), although it is generally believed that inefficient shotfiring is more productive of fumes.

The presence of water in the shot-hole usually has the effect of reducing the volume of nitrous fumes emitted (WOOD, 1957) although CORBETT and TIETZ (1951) have reported the opposite effect. The same authors found that the softer the material that is being blasted the greater the volume of nitrous fumes ensuing. This would help to explain differences found between concentrations in the softer coal and the harder rock workings.

Although a level of 810 p.p.m. oxides of nitrogen has been recorded in tunnels, a figure of 245 p.p.m. would seem to be more representative of maximum levels likely to be encountered. It should be noted, however, that many of these results have been taken from American sources or from measurements made in British coal mines before the War. The types of explosive in use have changed and the amount of explosive fired has greatly increased since then. Full measurements under a variety of modern conditions are required.

Methods of measuring the concentration of oxides of nitrogen

There are a number of methods available for measuring concentrations. Among these are the Griess–Ilosvay (and its various modifications); phenol-di-sulphonic acid; naphthylethylene diamine; 2:4 xylenol; chloranil; polarographic and Saltzman.

The chloranil, and the unmodified Griess–Ilosvay methods are said to be inaccurate where gas concentrations are low, and certain of the others to be complex and time consuming. Some of the methods unselectively pick up other nitrogenous compounds in the atmosphere with misleading results. Among these are oxides of nitrogen likely to be of small toxicological interest, nitric and nitrous acids, nitroglycerine, etc. (CHOLAK and McNARY, 1943; PATTY, 1949).

If considerable time elapses between sampling and analysis, as may happen when samples are transported from the coal face to the surface, then chemical reactions may take place between the components of the gaseous mixture. Among the reactions which may be expected to take place are: oxidation of NO to NO_2; combination between NO_2 and CO to give CO_2 and NO; and dissociation of the higher oxides, e.g. N_2O_3 to give NO_2 and NO.

A simple, speedy and accurate method for use below ground is needed. Such a method should enable low concentrations of the two main oxides to be measured separately. It would appear that the SALTZMAN (1954) method is the most suitable.

3. PHYSIOLOGICAL ACTION OF THE OXIDES OF NITROGEN

(1) *Mode of action of nitrogen dioxide*

At body temperature, i.e. at about 37 °C, the constituents of the $NO_2 : N_2O_4$ equilibrium mixture are approximately in the proportion of 3: 7 (HENDERSON and HAGGARD, 1943). On absorption into the body they appear to have these main effects:

(i) direct local irritant action on the lung surfaces, and

(ii) systemic disturbances through (a) nitrite and (b) methaemoglobin formation.

(i) *Direct local irritant action.* There is fairly general agreement among authorities on the mode of action. In solution the dioxide produces a mixture of nitric (HNO_3) and nitrous (HNO_2) acids. PATTY (1949) believes that the reaction proceeds fairly slowly; WIRTH (1930) states that it takes place quickly. In alkaline solution the corresponding salts are formed, i.e. nitrates and nitrites (BRINER *et al.*, 1922; FAIRHALL, 1949).

During inhalation of the relatively dry gas there may be little reaction between it and the respiratory passages. PATTLE and his colleagues (1957), for example, found little tracheal damage in their experiments on animals, but GRAY *et al.* (1952) describe an inflammatory condition extending throughout the respiratory tract. On reaching the alveoli the gas becomes increasingly humid so that the speed of reaction increases. At the moist surfaces of the mucosae "almost complete hydrolysis takes place" (PATTY, 1949) giving rise to nitric and nitrous acids. The acids react with alkalis in the alveolar tissue to give nitrates and nitrites, chiefly of sodium (HENDERSON and HAGGARD, 1943). In consequence there is destruction and severe irritation of the tissue. This, in turn, increases the permeability of the capillaries, with the result that there is a considerable extravasation of fluid into the alveolar spaces. A two- or four-fold increase in lung weight of animals exposed has been demonstrated (LA TOWSKY *et al.*, 1941). This extravasation may be so great that the casualty "drowns" in his own fluid.

Dyspnoea and respiratory arrest may arise through the irritant action of the acids on the pulmonary mucosa leading to spasm of the bronchioles (VON OETTINGEN, 1941). PATTY (1949) and SCHULTZ-BRAUN (1930) describe this as "asphyxial convulsions and respiratory arrest analogous to phosgene poisoning," but there is some doubt whether this analogy is justified (POTTS *et al.*, 1949; BOYD and STEWART, 1953). Respiratory arrest may also occur through interference to the Hering-Brauer reflex leading to diminished aeration of the lung (FLEMING, 1943).

(ii) *Systemic disturbances.* The nitrite formed by the action of acids on tissue alkali has a specific action (HENDERSON and HAGGARD, 1943). Dilatation of the blood vessels takes place, either through direct relaxant action on the smooth

muscle of the vascular walls (LA TOWSKY *et al.*, 1941) or by local reflex action (VON OETTINGEN, 1941). Consequently, blood pressure falls. Coalface officials, i.e. deputies and shotfirers, have not infrequently shown symptoms of headaches and vertigo (POWELL, 1956). SOLLMAN (1913) considers these are due to this fall in blood pressure. Associated with the fall in blood pressure is a compensatory increase in heart rate.

TOLLMAN *et al.* (1941) mention the possibility of a direct nitrite effect on the respiratory centre, and many writers have shown that diminished oxygen supply paralyzes it. There may also be an indirect action via the chemoreceptors of the carotid body and the aorta.

A consequence of the extravasation of fluid from the blood into the lungs is an increase in blood concentration; i.e., the ratio of blood corpuscles to total blood volume is increased. UNDERHILL (1920) concluded that such an increase in blood cell concentration is the direct cause of death by irritant gases. HÖLSTE (1937) assumed that the increase in blood concentration was brought about by haemopoesis, but this is said to have been disproved (VON OETTINGEN, 1941). However, BARCROFT *et al.* (1925) stated that carbon monoxide poisoning stimulated contraction of the spleen so that erythrocytes were sent into the blood stream. This may well occur in nitrogen dioxide poisoning.

In very severe cases nitric acid has been found in the blood (MCNALLY, 1937) with consequent haemolysis (MÜLLER, 1921).

Many authors have described the presence of methaemoglobin in the blood of animals and men who have been poisoned by NO_2, but there is no full account of the mechanism of its formation. MAKGILL and his co-workers (1897) demonstrated that animals poisoned with sodium nitrite showed the presence of methaemoglobin in the blood. MEIR (1925) found that, in alkaline solution, nitrite had little or no effect on oxyhaemoglobin; in neutral, or weakly acid solution methaemoglobin was formed. It is not clear whether the nitrite is the sole agent in methaemoglobin formation or whether the acids themselves play some part. It is also possible that nitrates may have an influence but this has been denied (HAMILTON and HARDY, 1949). Further there remains the possibility—as yet unexplored experimentally—that methaemoglobin is produced by NO alone.

Some writers are of the opinion that Nitric-Oxide-haemoglobin (NO-haemoglobin) is formed in addition to methaemoglobin. HARTRIDGE (1920) found that NO-haemoglobin was formed when nitrites acted upon haemoglobin. MEIR (1925) states this occurs only in weakly acid, or neutral, media with an excess of nitrite. GIBSON and ROUGHTEN (1955) state that NO has a very high affinity for haemoglobin. VON OETTINGEN (1941) considers that NO-haemoglobin formation in the blood can be explained by decomposition of excess nitrite into nitrate and NO, the remaining nitrite being used to produce methaemoglobin. The methaemoglobin, in turn, combined with the NO to give NO-haemoglobin. This reaction takes place only in the absence of oxygen, i.e., after death or after storage of blood from poisoned animals. But JACOBS (1949) states that under certain temperature conditions decomposition of NO_2 in the respiratory tract can yield NO. Thus there remains the possibility of formation from direct absorption of the gas. HERMANN (1865) stated that NO-haemoglobin can be found in the animal body, but BELKY (1886) considered that it is found only after death. (*Vide* ANSON and MIRSKY, 1925.)

Although NO-haemoglobin has not otherwise been reported in experimental animal exposures, perhaps because it has been overlooked, prima facie its formation in the body would appear to be possible. Research into the question is needed.

There is general agreement among authorities that the effect of methaemoglobin (and NO-haemoglobin) is anoxia, analagous to CO poisoning, and that with severe anoxia blood pressure will rise—thus offsetting and obscuring the nitrite reaction.

(2) *Mode of action of nitric oxide*

HALDANE and PRIESTLY (1935) stated that "as NO combined at once with air to form nitrous fumes (NO_2), nitric oxide poisoning, in the same sense as CO poisoning, is impossible". BODENSTEIN's work (1918) has shown that in low concentrations the reaction takes place slowly and PFLESSER (1935; 1936) has demonstrated poisoning by NO in animals. HALDANE's view is therefore no longer tenable.

WIRTH (1930) observes "in the case of poisoning by nitric oxide the formation of methaemoglobin is even more pronounced than with NO_2; NO poisoning also differs in the rapidity with which paralysis, spasm, and death occur. A characteristic symptom is marked cyanosis." WADE and his colleagues (1950) believe that the cyanosis is due to methaemoglobin formation: other workers ascribe this to NO-haemoglobin.

VON OETTINGEN (1941) suggests that the gas may have irritart properties but most writers follow PFLESSER (1935; 1936) in believing that it has not. There is fairly general agreement that its main action is combination with haemoglobin, thus reducing the amount available to carry oxygen. This single effect is in contrast with the threefold effect of the dioxide. There have been no direct reports of NO poisoning alone in man but ZADEK (1916) has suggested this might happen.

4. EFFECTS OF EXPERIMENTAL EXPOSURES TO NITROUS FUMES

(1) *Experiments on man*

HASEGAWA's experiments on himself (LEHMANN and HASEGAWA, 1912) are the only source of data about known levels of concentration and their effects on man. Nevertheless, this work is open to some objections. The gas used was nitric oxide and the experimenters expected this to be converted immediately to the dioxide. Three exposures only, on one man, were undertaken, in which different quantities of NO were released in a chamber of volume 11 m^3. Table 2 summarizes HASEGAWA's observations. The concentrations given have been calculated from LEHMANN's data. No corrections for temperature and pressure have been attempted as the necessary information is lacking.

It was not possible to calculate the concentration of NO_2 present at different times with any certainty. Not only would there be loss of concentration, probably caused by normal air changes in the experimental room, but there may well have been a rise in room temperature which would tend to increase the rate of formation of NO_2. None of these data are given.

The effects, except in the highest concentration, appear to be minor and no sequelae were reported.

TABLE 2. CONCENTRATIONS AND OBSERVED EFFECTS OF NITRIC OXIDE ON ONE MAN

Exposure no.	Total Duration (min)	Vol. of NO released (litres)	Concentrations (p.p.m.) measured at time intervals of:						Observations by HASEGAWA on himself:
			At start	After 10 min	20 min	60 min	90 min	100 min	
1	60	1·3	Not recorded	—	—	59	(end of exposure)		Slight irritation of larynx
2	120	4·5	97	—	97	74	41	22	Severe irritation of larynx: coughing
3	10	8	200	200	(end of exposure)				Severe irritation of larynx; coughing; suffocating feeling; headache; sickness; vertigo

Conclusions drawn from HASEGAWA's results and LEHMANN's interpretation of them are frequently quoted (*vide* GRAHAM and RUNNICLES, 1943; GRAHAM and LAWRENCE, 1948) as providing safe guides to levels of concentration encountered in coal mines. But deductions made from three tests on one man can have but little reliability, and conclusions drawn from the effects of the monoxide can have no valid application to those of the dioxide.

(2) *Animal experimentation* *

In Table 3 and the Appendices are summarized the most important results obtained, from experiments on animals, of the effects of single and prolonged exposures to nitrogen oxides. The results are taken from the following authors: DIGGLE and GAGE (1954); FLURY and ZERNIK (1931); GRAY *et al.* (1952, 1954; 1959); HALDANE and GRAHAM (1935); HAYNES (1941); HARROLD *et al.* (1940); IRVINE (1916); LEHMANN and HASEGAWA (1912); LA TOWSKY *et al.* (1941); MAC-QUIDDY *et al.* (1938); OHNESORG (1916); PFLESSER (1935, 1936); RONZANI (1908); TOLLMAN *et al.* (1941); VALADA (1951); and WIRTH (1930).

TABLE 3. CONCENTRATIONS OF NITROGEN OXIDES AND THEIR EFFECTS IN SINGLE AND PROLONGED EXPOSURES

Effect	Concentration (p.p.m.) at which effect appears in:			
	Single exposure	Of duration (hr)	Prolonged exposure	Of duration (hr)
No effect	Up to 34	4	Up to 4·3	384
Pulmonary damage	42	4	5–9·3	40–400
Some deaths	More than 53	2·5–4	More than 29	190

* The Appendices and other material have been deposited in the Central Library, Eccles, Lancs.

No deaths occurred nor was pulmonary damage reported when animals were exposed for 4 hr, on one occasion only, to concentrations below 42 p.p.m. Prolonged exposure of 400 hr produced, at 5 p.p.m. damage described by HAYNES (1941) as "serious lesions of the lungs". GRAY *et al.* (1952) found "emphysema and pneumonitis" at 9·3 p.p.m. after 40 hr total exposure. Some deaths in one species occurred, after a single exposure of 4 hr duration, at 53 p.p.m., and in two species at 29 p.p.m. on prolonged exposure of 190 hr.

Methaemoglobin was not reported below 100 p.p.m. in single exposures and 24 p.p.m. on prolonged exposures. Spectroscopic methods were used by many experimenters, but HALDANE *et al.* (1897) showed that methaemoglobin was not spectroscopically discernible until the blood saturation was 24 to 25 per cent. Using special methods McCORD *et al.* (1941) found methaemoglobin in blood saturations of only 2·3 per cent. Its presence therefore may have been overlooked by some experimenters, and there are of course species differences in the ability to reduce methaemoglobin to haemoglobin (NEILL, 1925).

Loss of weight in experimental animals on prolonged exposure was frequently reported.

It will be seen from Appendices A and B that there are considerable differences in the levels of toxicity reported by different authors. A measure of toxicity is given by the "c.t."—the product of concentration and time. Although c.t.'s have been calculated, partly because of the wide variations and partly because there are grounds for believing that the "c.t." alone is not a useful measure (KAREL and WESTON (1947)), they are not given here.

Part of the explanation of these variations in toxicity lies in differences among species of animals. Differences in volumes inhaled per minute must be expected to have an influence.

But there remain differences of some magnitude between the results reported on the same species. Among the reasons which may account for such variations are: differences in experimental technique and in methods of measuring the concentrations employed; variations in the source and composition of the gases to which animals were exposed; differences in physical constitution, age (*vide* STOKINGER, (1957)) and strain of the animals; and differences in ambient temperature—where reported they varied from 19° to 32 °C. The number of animals exposed in some experiments is very small—on occasions only one. Hence, the results may well be unreliable: cage differences are also well known and can affect results. Finally, controls were not used in all cases: neither were micropathological investigations always made.

(3) *Temperature and toxicity*

There is some evidence that toxicity increases as temperature rises. Table 4 below summarizes results taken from GRAY *et al.* (1954; 1959) and HARROLD *et al.* (1940) and shows the effect on rats of single exposure to high temperatures alone, nitrogen oxides alone, and high temperatures and nitrogen oxides combined.

It will be seen that high temperatures alone have no effect on rats, but in conjunction with nitrogen oxides the LC_{50} was reduced by 35 p.p.m. A similar effect has been observed on other species with carbon monoxide (SAYERS, *et al.*, 1922) and appears to be related to increased metabolic rates brought about by increased environmental temperatures.

TABLE 4. EFFECT OF SINGLE EXPOSURES TO NITROGEN OXIDES AND HIGH TEMPERATURES

Exposure	Duration of exposure (hr)	Concentration of nitrogen oxides (p.p.m.)	Mean temperature (°C)	Mortality ensuing (%)
High temperature alone	6·5	—	39·4	0
Nitrogen oxides alone	4	LC$_{50}$ 174	28	(50)
High temperatures and nitrogen oxides	4	LC$_{50}$ 139	39·2	(50)

Note: Mortality in Gray's results are expressed in terms of LC$_{50}$ for a 4 hr exposure.

However, on prolonged exposure the effect is less clear-cut, partly at least because full and comparable data are lacking. Results are obscured by the effect of heat adaptation. BEATTIE and CHAMBERS (1953), for example, showed that not less than 28 days continuous exposure was required for heat adaptation in rats at a temperature of $29·5 \pm 1$ °C. Species differences also appear—HARROLD *et al.* (1940) found that 6 out of 7 rabbits died after an exposure of 6·5 hr to an ambient temperature of 39·4 °C, whereas all of a batch of 10 rats survived.

Nevertheless, McCORD *et al.* (1941) found that 3 of a batch of 24 rats and 1 of 16 rabbits died when exposed to levels as low as 13 p.p.m. nitrogen oxides and 30 °–31·7 °C temperature for 276 hr.

It would seem desirable that further research be done on this problem as it may have practical application to conditions on coal faces.

(4) *Differences in toxicity between nitric oxide and nitrogen dioxide*

PFLESSER (1935; 1936) exposed mice to nitric oxide mixed with air, at different levels of concentration, and to nitrogen dioxide (oxidized from NO) and air at the same concentrations. He came to the conclusion that "nitric monoxide is about four times more poisonous than nitrogen dioxide and, for comparison, about thirty times more poisonous than carbon monoxide."

His work however does appear to be open to some objections. It is most probable that the animals were exposed to a mixture of NO and NO$_2$ and not to either gas alone, the monoxide being the main constituent. The levels of toxicity of nitrogen dioxide found by Pflesser, and used by him for comparison with nitric oxide, were far higher than those described by other authors; for example, when mice were exposed for 120 min to a concentration of 1200 p.p.m. there were no deaths. LA TOWSKY *et al.* (1941) on the other hand found, for the same exposure time to NO$_2$, that one-tenth approximately of this concentration was lethal to the same species. Exposures to "nitrogen dioxide" were not made below 1200 p.p.m. by PFLESSER.

Exposures of duration 4–8 hr had no effect below 310 p.p.m. NO and in no case was lung damage discovered although concentrations up to 4500 p.p.m. were employed. The number of animals used was very small—in 6 out of 19 experiments only one, so that the results are of uncertain reliability.

The evidence tends to the conclusion that NO$_2$ is the more dangerous, but it is desirable that further work be directed to the question.

5. INDUSTRIAL EXPERIENCE OF EXPOSURE TO NITROUS FUMES

(1) *Acute exposure*

The first reported case of poisoning by nitrous fumes was in 1804. There have been numerous examples recorded since then, but no attempt has been made to summarize them here because, although the symptoms are described, the concentrations at which these effects occurred were not measured. (By way of example *vide* the observations of BECKLAKE *et al.* (1957) on the acute effects of nitrous fumes produced by blasting in the South African goldmines.)

In view of the complexity of physiological response to the gases, and owing to the fact that mixtures of the monoxide and dioxide are encountered, a great variety of symptoms has been reported. FLURY and ZERNIK (1931) identify four main groups of effects (i) irritant, (ii) shock, (iii) reversible and (iv) combined— this last type containing elements of the other three groups.

The Irritant type is characterized (VON OETTINGEN, 1941) by coughing and choking immediately on exposure, followed by a "latent period" of from 5 to 24 hours whereupon pulmonary oedema often appears. HUNTER (1955) speaks of the "treacherous and insidious effects of the gas which can be breathed with only slight inconvenience in concentrations which will cause an acute suffocatory oedema after exposure of half to one hour and since the least concentration, which will provoke coughing, is very little less, the margin of safety is small". "Exertion however slight in these circumstances may produce collapse" (SOLLMAN, 1913). Hunter describes the initial symptoms as "irritation of eyes and throat, cough, tightness of the chest and nausea. There is a feeling of weakness and disinclination for any exertion." Many writers have suggested that a pneumonitis may occur several days, or even weeks, after exposure. LA TOWSKY *et al.* (1941) observe that "almost any type of lung infection is possible in theory", owing to increased bacterial growth in a lung where resistance has been lowered by the destructive action of the gas on the epithelial cells.

The Shock type is said to occur when there is sudden exposure to high concentrations of gas with consequent asphyxiation, convulsion and respiratory arrest.

PATTY (1949) states the characteristics of the Reversible type are "dyspnoea, vertigo, methaemoglobinaemia without pulmonary oedema." RABBENO and RAPPENPORT–LEVY (1936) say that death occurs when the blood is 80 per cent saturated with methaemoglobin. This estimate may be too high, for men killed by carbon monoxide after colliery explosions showed a CO-haemoglobin saturation of as little as 60 per cent (HALDANE and PRIESTLY, 1935).

It would be most unlikely that concentrations having such effects would be found underground under normal circumstances.

(2) *Prolonged exposure*

EDGAR (1905), HAMILTON (1945), the compilers of the INTERNATIONAL LABOUR OFFICE REVIEW (1923), LEGGE (1920), LÖSCHKE (1910), VIGORDTSCHIK *et al.* (1937) and WELSH (1920) state that among the effects of chronic poisoning, by low concentrations of nitrous fumes, are: erosion of the teeth and gums, irritation and inflammation of the eyes and upper respiratory tract, emphysema, pulmonary damage, circulatory and respiratory disturbance, indigestion, anaemia, vomiting,

malnutrition, and loss of weight. Many of these symptoms (as is the case with acute effects) have been observed on experimental animals.

Some authors consider that the main effect of chronic poisoning is the systemic action of the nitrite—an effect often obscured in high concentrations by the irritant action of the fumes. But others (HAMILTON and HARDY, 1949) think that prolonged pulmonary irritation is the most important factor. Although LEHMANN and HASEGAWA (1912) isolated nitrites from the tissues of exposed animals these were not, apparently, in sufficient quantity to bring about the systemic nitrite reaction. HENDERSON and HAGGARD (1943) hold that an habituation to the nitrite reaction can be developed (when exposed to low concentrations) but not to the irritant effects. Reports of symptoms, however, suggest that both the nitrite and irritant reactions may occur. Methaemoglobin has been reported, but WADE et al. (1950) state that "its effects in small amounts, as far as is known, are minor."

HENDERSON and HAGGARD (1943) say that "it is impossible to speak with positiveness about the effect of continued exposure—it may lead to chronic pulmonary disease." LEGGE (1920) and HALDANE et al. (1904, 1935) believed this may happen. WELSH (1920) concluded that there is a direct connection between the length of exposure to fumes and a gradual increase in pulmonary disability. STAAB and ZANGER (1915) considered that dormant tubercular conditions may be reactivated. ROBSON and his colleagues (1934) suggested a pneumonitis occurred on prolonged inhalation. Their arguments were supported by animal experiments, but they exposed the animals to a mixture of sulphur dioxide and nitrous fumes. This evidence, therefore, is not directly relevant.

It seems that although there is fairly good agreement among authorities that the main effect of prolonged exposure, at low concentrations, is pulmonary irritation, there is no great weight of industrial evidence to give direct support to this view.

Table 5 summarizes the evidence available from industrial medical experience of the effects of low levels of concentration on men exposed for long periods. In some instances toxic materials other than oxides of nitrogen may have been present.

There is considerable difference of opinion among authorities, sufficient, it would appear, to warrant further investigation. The question of chronic poisoning is of direct relevance to conditions below ground during shotfiring.

MAXIMUM ALLOWABLE CONCENTRATIONS OF OXIDES OF NITROGEN

The Maximum Allowable Concentration (M.A.C.) is defined as "the concentration to which a worker can be exposed for eight hours a day for indefinite periods without injury." There is some controversy among authorities as to which represents a safe standard. Table 6 below gives some examples of M.A.C.s proposed by various authorities for use in industry.

Good modern industrial practice aims at 10 p.p.m. But the results of recent and well-directed animal experimentation, taken in conjunction with reports from industrial experience, suggest that damage can be caused at a very low level of concentration, so that even this standard may be too high. There are no comparable standards in the mining industry.

TABLE 5. INDUSTRIAL EXPERIENCE OF CHRONIC EXPOSURE

Author	Source of oxides of nitrogen	Calculated concentration of oxides of nitrogen (p.p.m.)	Condition and exposure time
VIGORDTSCHIK et al. (1937)	Acid fumes	2·5	127 men exposed to such a concentration for 3–5 years showed evidence of chronic poisoning
DADLEZ (1927)	Arc lamp	5	No irritation to nose or throat in 30 min
McCORD et al. (1941)	Welding fumes	3·9–5·4	2·3–2·6 per cent methaemoglobin in blood of welders exposed to such concentrations for long periods
NEWMAN (1930)	X-ray apparatus	7·5–38·5	Headaches in X-ray operators
DRESSEN et al. (1946)	Arc welding fumes	Less than 10	Lowered blood pressure in welders
PATTY (1949)	Nitric acid fumes average range	10–20 5–30	Men exposed for 6–8 hr per day for 18 months to such concentrations showed no ill-effects
GOLDBLATT (1955)	—	30	If exposed for more than a short time may lead to symptoms of illness
DADLEZ (1927)	Arc lamp	55–84	Irritation to nose and throat
HARROLD et al. (1940)	Welding fumes	70	Threshold of harmful concentrations of oxides of nitrogen present in welding fumes, for prolonged exposures
HALDANE and GRAHAM (1935)	—	100	Fatal if breathed for an hour daily
GOLDBLATT (1955)	—	100	If exposed for 1 hr, severe toxic effects
ZHĪTKOVA (1936)	Acid fumes	675	Numerous cases of poisoning

6. EFFECTS OF NITROUS FUMES IN CONJUNCTION WITH CARBON MONOXIDE AND OTHER TOXIC AGENTS

The colliery officials who are responsible for conducting blasting operations in mining are the deputies and shotfirers. These officials are exposed to nitroglycerine, and to a much lesser extent α-Trinitrololuene, from handling the explosive before firing (POWELL, 1956) as well as to nitrogen oxides and carbon monoxide from the detonation. The question arises concerning their combined influence. The following Table 7, summarizes the probable systemic effects of these toxic factors.

These toxic agents are likely to be present simultaneously in the bloodstream of shotfirers. Their effects *in toto* will be complex. To a certain extent they can be expected to reinforce one another but there is no evidence that the reinforcement is synergistic. Yet there may be instability and competition among them, as, for example, between NO and CO for haemoglobin: GIBSON and ROUGHTEN (1955) state that the affinity of haemoglobin for NO is 1000 times that for CO. Long term effects may be even more complex, for acclimatization to CO poisoning has

been reported, as has an habituation to nitroglycerine and to the nitrite reaction of oxides of nitrogen. Further work is needed to elucidate these problems.

TABLE 6. MAXIMUM ALLOWABLE CONCENTRATIONS PROPOSED

| Source of industry | Standard proposed (p.p.m.) for: | |
	Nitrogen dioxide only	Oxides of nitrogen
ZHĪTKOVA (1936). U.S.S.R. Standards	—	1·5–2·5
ELKINS (1946)	5 or less	—
AMERICAN CONFERENCE OF GOVERNMENTAL INDUSTRIAL HYGIENISTS (1953)	. 5	—
GOLDBLATT (1955). Imperial Chemical Industries Standards	10	—
MASSACHUSSETS DEPT. OF LABOUR AND INDUSTRIES (1947)	10	—
DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH (1953)	10	—
AMERICAN STANDARDS ASSOCIATION (1944)	—	25
BUREAU OF MINES (JOHNSON et al. 1940)	—	33
NEW YORK STATE DEPT. OF LABOUR (1945)	—	40
PATTY (1949)	—	70

TABLE 7. SYSTEMATIC EFFECTS OF THE TOXIC AGENTS TO WHICH SHOTFIRERS ARE EXPOSED

Toxic factor	Probable mode of action	Consequent systemic effect
Nitroglycerine Nitrogen dioxide Nitrogen monoxide	Nitrite effect	Vasodilation with fall in blood pressure
α–T.N.T.	Direct action	
Nitroglycerine α–T.N.T. Nitrogen dioxide Nitrogen monoxide	Methaemoglobin formation	Reduction in oxygen-carrying power of blood
Nitrogen dioxide Nitrogen monoxide	Possible NO-haemoglobin formation	
Carbon monoxide	CO-haemoglobin	

Some evidence is available on the effects of gas mixtures. WIRTH (1930) summarizes work done, under FLURY'S direction, on the problem; an example is the work of HOFER (1925) who found that a carbon monoxide–hydrogen cyanide mixture had a greater effect than double the concentration of either constituent alone. More recently MOSS and his collaborators (1951) have experimented with similar mixtures.

WIRTH exposed cats, on one occasion only, to different concentrations of carbon monoxide and nitrogen dioxide, and then to mixtures of the gases. He compared the average time to cause death in the different conditions. The time for

death was greatest with carbon monoxide, less with nitrogen dioxide and least with the mixtures: for example at 480 p.p.m. CO the mean death time was 51 min; at 1550 p.p.m. NO_2 the time was 37 min ; and for a mixture of 480 p.p.m. CO and 1550 p.p.m. NO_2 (total toxic material—6400 p.p.m.) the time was 24 min. He concluded that a mixture of CO and NO_2 was more toxic than either gas alone.

PATTLE *et al.* (1957; 1959) exposed mice and guinea-pigs to the fumes of a diesel engine. No control runs on CO or NO_2 alone were made but, whereas LA TOWSKY *et al.* (1941) found a low mortality in such species at 55 p.p.m. NO_2 alone, PATTLE'S results show a high mortality at approximately the same level (i.e., 51 p.p.m. NO_2) when 410 p.p.m. CO were also present.

Pattle also showed that where 5 hr exposure to a mixture of 23 p.p.m. NO_2 and 560 p.p.m. CO had no effect, a prolonged exposure of 14 hr at roughly the same concentration caused a high mortality rate.

IRVINE'S experience (1916) in the South African gold mines led him to conclude that a condition of dual poisoning was unlikely. No case came to his notice, but no haematological investigations were made. WIRTH however has reported that carboxy and methaemoglobin occurred together in the blood of some of the specimens exposed to mixtures of CO and NO_2.

There are however some difficulties in the way of assessing the results described in the previous paragraphs. In PATTLE'S work some nitric oxide was also present (although not measured in terms of the dioxide) as well as aldehydes.

WIRTH used nitric oxide as the source of fumes, expecting it to be quickly converted to the dioxide. His results, expressed as p.p.m. of NO_2, therefore refer to an unknown, yet, in all probability, high proportion of NO. Hence, the levels of toxicity for NO_2 alone found by WIRTH are much greater than those reported by other workers. The same appears to be true for the gas mixtures where the animals were exposed to greater total concentrations of toxic material than with either pure gas.

On balance the evidence suggests that mixtures of carbon monoxide and oxides of nitrogen are more dangerous than either gas alone, and prolonged exposure is likely to have more serious effects. But further work seems desirable for, as carbon monoxide and nitrogen oxides occur together in shotfiring fumes, the problem of their combined effect is of practical importance.

8. EXPOSURE IN UNDERGROUND WORK PLACES

The rate at which shots* are fired, the amount and type of explosive used, the speed and quantity of ventilating air, and the geological conditions obtaining, all affect the level of concentration of fumes and differ considerably between the places where most shotfiring takes place, that is, on coal faces and in headings and tunnels. Other factors affecting exposure which must be taken into account are the method of working and the system of shotfiring.

(1) *Exposure on coal faces*

On coal faces shots are generally fired intermittently throughout the working shift. From a sample of 12 collieries it was found recently that the number

*A shot is one charge of explosive.

of shots fired per coal face in a shift averaged 108, the mean weight of explosive in each shot was 9 oz, and the total weight of explosive fired in the shift averaged 62·5 lb. Shotfiring practice varies considerably but in general there are two main systems. In the first the bulk of the shots are fired during the preparation shift when there are few men, other than shotfirers, on the face. The remainder are fired in the filling shift. In the other system a number of shots are fired at the commencement of the filling shift to allow the colliers to "break into" their stints. Afterwards occasional shots are fired to help men in difficulties. Later there is an increase in shotfiring activity in order to loosen remaining hard material.

Air for ventilating the face enters through an intake at one end and leaves at the other via a "return". Fumes will thus be diluted and swept along the face and carried away through the main return airway. There will be differences in exposure according to position on the face, for men working near the intake will be much less exposed than those at the return.

When a shot is fired the bulk of the fumes forms a "cloud" which travels along the face under the impulsion of the air current. Field observations (GRAHAM and RUNNICLES, 1943) and laboratory trials (CLAEYS, 1957) have shown that a small fraction is trapped and absorbed in the debris of the explosion to be later emitted slowly (GRAHAM and RUNNICLES, 1943). Both the leading and trailing edges of the plug are visibly attenuated and the smoke cloud will become increasingly mixed with air owing to the turbulent nature of the air current. Thus both the peak concentration and the transit time of the plug will be related to the velocity of the air and the distance from the point of explosion. (*Vide* HODKINSON and LEACH, 1958.)

It would seem therefore that men on the coal face will be exposed almost continuously to a low level of concentration with intermittent brief exposure to higher levels. Before the war GRAHAM and RUNNICLES (1943) found an average concentration throughout the working shift of about 5 p.p.m. of oxides of nitrogen but peak concentrations of 56 p.p.m. were measured. Mean concentrations measured recently (*vide* Table 1) were 25 p.p.m. with peaks of 75 p.p.m. oxides of nitrogen.

There are usually however sections at either end of the coal face, known as "fast ends" or "corners" where the work place forms a cul-de-sac and where there is little air velocity. A concentration of fumes may tend to increase gradually during the shift. It will be seen from Table 1 that the concentrations here are higher than on the main section of the face.

(2) *Exposure in headings and tunnels*

Shotfiring practice in headings and tunnels differs from that on coal faces. A group of shots are fired together, one such round commonly being fired in a working day. In tunnels 70–90 or more lb of explosive are fired in a round but in headings considerably less, 6–10 lb often being used in the working shift. As the work place has the form of a cul-de-sac, through ventilation is not possible and ventilating air, under pressure, is led to the tunnel face by pipes of large diameter. (An alternative method is to exhaust the air, and consequently fumes and dust, by suction through such pipes.) When the round is fired the cloud of fumes drifts slowly towards the open end of the tunnel, or heading, forced by the pressure of the air from behind.

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There will be a high initial concentration, followed by gradual diminution —the rate of which will depend partly on the quantity of ventilating air and partly on the weight of explosive fired. Men are, of course, withdrawn from the area during shotfiring, and regulations require an interval of ten minutes before men are allowed to return to the place where a round of more than six shots has been fired (five minutes for six shots or less). This will normally prevent men from working in the fumes when at their worst, especially if exhaust ventilation is operated. However, men will be working in residual fumes and will thus be exposed to varying levels of concentration. In recent tests made in tunnels the maximum amount of oxides of nitrogen and carbon monoxide measured one minute after firing were 245 p.p.m. and 1060 p.p.m. respectively, declining to 20 p.p.m. of oxides of nitrogen and 145 p.p.m. of carbon monoxide fifteen minutes later.

(3) *Toxic levels underground*

Table 8 summarizes information available on the level of concentration of oxides of nitrogen and carbon monoxide and the type of exposure.

TABLE 8. EXPOSURE IN UNDERGROUND WORK PLACES

Work place	Exposure		At time of Shotfiring general level of concentration of:		During shotfiring peak concentrations of:	
	Frequency	Type	Oxides of nitrogen (p.p.m.)	Carbon monoxide (p.p.m.)	Oxides of nitrogen (p.p.m.)	Carbon monoxide (p.p.m)
Coal face— main section	Repeated: prolonged in the shift	Continuous low level: frequent peaks of higher concentration	25	40	75	90
Coal face— fast ends	Repeated: prolonged in the shift	Tendency for gradual build-up of concentration during the shift	142	600	172	700
Headings	Repeated usually not more than once in a working shift	Rapid diminution from high initial level	—	—	172	360
Tunnels	Repeated usually not more than once in a working shift	Rapid diminution from very high initial level	—	—	245	1060

Concentrations causing acute effects are unlikely to be encountered underground. The general type of exposure is prolonged at a comparatively low level of concentration. (But *vide* H.M. Inspectorate of Mines, 1955.)

Animal experimentation has indicated that prolonged exposure causes lung damage in animals at 5–9 p.p.m. NO_2. Evidence from industrial experience is conflicting, but good modern practice is to fix a Maximum Allowable Concentration for an 8 hr exposure of 10 p.p.m. NO_2 (and 100 p.p.m. of carbon monoxide).

There are some difficulties in the way of applying this experience to mining conditions. First, all underground measurements quoted are in terms of total oxides of nitrogen. They will thus include the probably less toxic NO. Also there may be errors introduced owing to the different chemical methods of analysis used. Other nitrogenous groups in the atmosphere may also be unselectively picked up and included. Hence the dioxide, probably the most dangerous component of nitrous fumes, is likely to be less than the measured concentration. A few measurements made by GRAHAM and LAWRENCE (1948) suggest that the ratio of NO and NO_2 in shotfiring fumes soon after the explosion is of the order of 2 : 1. With oxidation this ratio will decrease in time. Differences in the amount of wax used on the cartridge may affect this ratio, for it has been found (CORBETT and TIETZ, 1951) that waxing causes a severe oxygen deficiency on explosion so that the lower oxides would be produced in greater quantity. (Similar considerations apply to the production of carbon monoxide and dioxide.) The temperature of the environment will also affect the ratio, for increased temperature will increase the rate of oxidation of NO.

Secondly, evidence of the combined effect (which may be exacerbated by other toxic factors) of carbon monoxide and oxides of nitrogen suggests that effects may be seen at a lower level than with either gas alone. The question remains open concerning the long term effects, although there is some suggestion that they may be more severe.

Thirdly, there appears to be a real increase in toxicity, with a rise in environmental temperature, for both carbon monoxide and nitrogen dioxide. The level at which this effect becomes marked is not clear.

Finally, such general standards cannot take into account such factors as occupational differences, with their wide differences in rates of working, nor individual differences in susceptibility owing to age, health, etc., which occur in the mining industry.

SUMMARY AND CONCLUSIONS

(1) The most important gases produced when explosives are detonated are carbon monoxide and oxides of nitrogen. The oxides of nitrogen of significance appear to be nitric oxide and nitrogen dioxide; these constitute what are commonly known as "nitrous fumes".

(2) The oxides of nitrogen have complex physiological effects.

(3) In general there is agreement among authorities on the mode of action of nitrogen dioxide but not about those of nitric oxide. There is controversy also over which is the more toxic. On balance the data suggest that the dioxide is the more dangerous.

(4) There is much evidence concerning the effects on man of single exposure to oxides of nitrogen, but none of the actual concentrations of gas at which these effects occurred. HASEGAWA'S experiments on himself are the only experiments m ι n, but the conclusions he drew do not appear to be valid, although in

reports dealing with shotfiring fumes in coal mines HASEGAWA'S results seem to have been accepted as providing safe standards of concentration.

(5) Many experiments on the effect of single exposures have been made on animals, but only those made recently appear to be well controlled and to give reliable data. Results of such recent work indicate that below about 42 parts per million (p.p.m.) of nitrogen dioxide no deaths are caused, nor is pulmonary damage seen in lower animals, namely rats, mice and guinea-pigs.

Rats and guinea-pigs, exposed repeatedly or continuously over long periods, show lung damage when the concentration of nitrous fumes is higher than 5–9 p.p.m.

(6) Evidence from industrial experience is conflicting. Russian workers claim to have demonstrated chronic pulmonary, haemotological and other changes in men exposed for long periods to only 2·6 p.p.m., but some American authorities consider that 70 p.p.m. is the threshold of harmful concentration. Many are convinced that chronic pulmonary conditions are the outcome of repeated exposures although the evidence for this does not appear to be strong.

(7) The Maximum Allowable Concentration is defined as "the concentration to which a worker can be exposed for 8 hr a day, for indefinite periods without injury". Modern factory practice is to fix a standard of not more than 10 p.p.m. of nitrogen dioxide. There are no comparable standards in coal mining.

(8) The pattern of exposure underground depends on a number of factors and varies with the place and the method of work. On coalfaces, where a significant amount of shotfiring occurs, it would seem that throughout the shift men at work are exposed to a low concentration of oxides of nitrogen, with intermittent peaks when shots are fired. In tunnels and similar workings, much the same applies. The significance of such exposure as a health hazard cannot accurately be assessed.

(9) Application of the results of animal experimentation and industrial experience to coal-mining conditions is difficult. Among the reasons are: (a) there are other toxic agents present in gases from explosion, chief of which is carbon monoxide. The suggestion has been advanced that mixtures of carbon monoxide and oxides of nitrogen are more dangerous than either gas is alone. There are other toxic agents, nitroglycerine and α-T.N.T., to which shotfirers are exposed whose effects may reinforce those of the gases but whose long term results are complex and obscure; (b) there is some evidence that the toxicity of nitrogen dioxide (and carbon monoxide) increases as environmental temperature rises; (c) the measurements of concentrations below ground are given in terms of total oxides of nitrogen. Apart from errors introduced by the chemical methods employed, such concentration will contain a proportion of the probably less dangerous nitric oxide, which is only slowly oxydized to the dioxide. The measurements may well not represent the true level of exposure. Nevertheless the concentrations measured do appear to warrant further and wider investigations.

A pilot project is being considered with the object of obtaining, by selective sampling, a clearer indication of the levels of concentration of nitrogen dioxide in work places underground.

Note—The views expressed in this paper are those of the author and are not necessarily those of the National Coal Board.

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FILTER-PAPER METHODS OF
AIRBORNE-DUST MEASUREMENT IN COAL MINES

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Abstract.—In 1948, a filter-paper method of measuring airborne-dust concentrations on coal-faces, by means of a handpump and densitometer, was introduced. A review is given of various attempts to improve the method by developing a new handpump and long-period samplers with particle size selection, and by evolving the "*S*-scale" of dust stain density which, for black particles larger than $1\,\mu$, is proportional to their total projected area. The calibration factor relating stain density to particle-number or weight depends both on size distribution and degree of transparency.

Underground tests on the correlation of the improved methods with the thermal precipitator and Hexhlet sampler are described. The stain density was found to give only a very rough estimate of particle number or weight concentration (95 per cent confidence limits about 40–250 per cent). This variability in calibration factor was more than random instrumental errors of measurement, or variations in the composition and size distribution of the dust, could account for.

However, in a given dust cloud the reproducibility of the stain density measurement was better than that of the particle number measurement by thermal precipitator. Consequently the filter-paper method is of value in permitting larger numbers of comparative dust measurements at a given working place to be made economically.

1. INTRODUCTION

In 1948 a scheme of airborne dust sampling based on the thermal precipitator (Watson, 1936) was agreed upon for British coal mines. Since the thermal precipitator involves much labour both in taking the samples underground and in evaluating them by microscope in the laboratory, Watson and Hounam (1948) developed a simpler system of airborne dust measurement, the Pneumoconiosis Research Unit (P.R.U.) handpump outfit, in order that more dust samples might be taken for a given effort. A sample of mine air was drawn through a filter-paper by a number of strokes of a handpump, and the density of the dust stain was measured by a simple densitometer in which the paper was interposed between a small tungsten-filament lamp and a selenium photocell connected to a microammeter. The number N of dust particles per cm^3 of air as measured by the thermal precipitator was said to be related to the densitometer measurement by the formula

$$Nn = 100C(\log_{10}i_o/i)^x \qquad (1)$$

where n is the number of 80 cm^3 handpump strokes, C and x are calibration constants, and i_o and i are the densitometer currents with a $\frac{3}{8}$ in diameter Whatman no. 1 filter-paper clean and stained respectively. In a comparison of simultaneous measurements by the P.R.U. handpump and the thermal precipitator (particle size range 0.5–$5\,\mu$) in a number of collieries, chiefly in South Wales, Watson and Hounam (1948) found a value 1.5 for the index x and a range of 1100–4750 in the coefficient C.

It was agreed that airborne dust samples might be taken by the P.R.U. hand-pump wherever it could be shown that the number of particles per cm^3 of air deduced from equation (1) was in reasonable agreement with a direct measurement by thermal precipitator. The handpump came into widespread use, and during the next few years the annual number of samples taken with it rose to more than a million, about ten times the number taken by thermal precipitator at the time.

It soon became evident, however, that the prediction of particle number concentrations from the empirical formula (1) was not always reliable (DAVIES and AYLWARD, 1949; WATSON, 1952; CATCHPOLE *et al.*, 1952; DAWES, 1954b; PATIGNY and CARTIGNY, 1954) and the P.R.U. handpump has largely fallen into disuse. Since the advantages of easy sampling were not lightly to be discarded, however, efforts were made to improve the sampling apparatus and the method of calibration (LLOYD, 1950; COLLIERY ENGINEERING, 1951; DAVIES and AYLWARD, 1951; POTTER, 1952; DAWES *et al.*, 1954, 1961; WINDER, 1960). This paper reviews these attempts and reports laboratory and underground studies of the measurement of airborne dust by an improved filter-paper method. It is concluded that its inherent variability in measuring the number, surface area, or weight of particles is large, and that it is useful only for rough estimates of concentration. For the more limited purpose of comparing concentrations it is of more value since its reproducibility of measurement is better than that of the thermal precipitator.

2. THE LIGHT TRANSMISSION OF FILTER-PAPER DUST SAMPLES

Provided filter-paper is a perfect diffuser of light, any further scattering of light by dust particles on or in the paper has no effect on the proportion of the incident light which passes through the paper and reaches the photocell. The loss of light due to the particles arises entirely from absorption in the particles themselves. Calculations by JOHNSON *et al.* (1954) and by HAUGEN (1952) show that, for black particles larger than about $1\,\mu$, the amount of light absorbed is approximately equal to that geometrically incident upon them. Below $1\,\mu$ the light-absorbing power of particles decreases, as does the efficiency of their collection by filter-paper; fortunately the projected area of the sub-micron particles in mine dust is usually only a small proportion of the total area of all the respirable particles, and the small contribution of the sub-micron dust may therefore be neglected.

The light loss due to particles larger than $1\,\mu$ is therefore equal to the geometrical area which they screen, in relation to the area of the paper, and this has been confirmed experimentally by DAVIES and AYLWARD (1949, 1951) for filter-paper samples taken in a laboratory coal-dust cloud. For dense dusts deposits a correction must be applied for particle overlap. Assuming random deposition of particles, DAVIES and AYLWARD (1951) derived a simple exponential relationship $\pi \nu D^2/4 = -\log_e i/i_o$, where ν is the total number of particles of root-mean-square diameter D on $1\,cm^2$ of paper. For $i/i_o > 0.2$ this fitted the experimental results for an esparto paper.

DAWES (1954a) pointed out that the particles did not deposit completely at random over the paper but preferentially in regions of greater permeability, and

evolved the "S-scale" of optical density to allow for this. If the dust stain density S is defined as

$$S \equiv 100(\log_{10} \log_{10} 100 - \log_{10} \log_{10} 100 i/i_o),$$

then it was found experimentally that

$$\pi \nu D^2/4 = 0 \cdot 1065 S$$

for coal-dust samples down to $i/i_o = 0 \cdot 06$, for the same and another esparto paper. Thus by means of a simple chart the S value, which was proportional to the total area of particles in the sample, could quickly be found from the densitometer readings for the clean and stained papers.

Although these formulae give a satisfactory means of deducing the total projected area ($\pi \nu D^2/4$) of light-absorbing particles on a filter-paper, the relation between the number ν of particles larger than about 1μ and the densitometer measurements clearly varies with the size-distribution, since

$$\nu = 0 \cdot 135 S/D^2 \equiv k_o S.$$

If in addition the particles are not opaque, and many coal particles transmit light at sizes approaching 1μ, the calibration factor k_o will show still more variation.

3. THE AIR-PERMEABILITY OF FILTER-PAPER DUST SAMPLES

Since there is a large difference between the stain density of equal numbers of opaque and transparent particles of equal size, the possibility was investigated of evaluating the sample by measuring the decrease in the air-permeability of the paper due to clogging by the dust. It was also hoped that by comparing the optical and permeability measurements on a filter-paper sample some indication of the composition of the dust, or at least of changes in composition from one sample to another, might be given. However the method gave anomalous results in the laboratory, and in the underground tests its variability was no less than that of the optical density method. Consequently the air-permeability method was abandoned (HODKINSON, 1961).

4. IMPROVED FILTER-PAPER DUST SAMPLING INSTRUMENTS

If particles considerably larger than those in the respirable size range can reach the filter-paper, they provide a large and variable proportion of the total particle surface area (WALTON, 1954). To avoid this disadvantage, DAWES et al. (1961) developed a size-selecting handpump. The unwanted coarse dust collected in a settling chamber before the air passed through the filter-paper, the settling period of 6 seconds being governed by a pneumatically regulated return stroke.

Since handpumps obtain their dust sample in a few minutes, a large number of samples must be taken at intervals if an average dust concentration is required. This is avoided by using the long-period filter-paper sampler of WINDER (1960).

A drum pump, consisting of a set of vanes half immersed in water and rotated by clockwork, draws air upwards through a $\frac{3}{4}$ in. diameter horizontal filter-paper (area $0 \cdot 71$ cm^2) at 6 cm^3/min: the coarse particles sediment too quickly to be carried up to the paper by such a low air velocity. In the present underground tests these dust samples were found to be insufficiently dense. The diameter of the paper was therefore reduced to $\frac{3}{16}$ in. and the same size selection was achieved by sampling the air through a small horizontal duct.

Although the long-period sampler draws air through the filter-paper at less than 1 per cent of the speed in the handpump, DAWES *et al.* (1954) showed, by experiments in a laboratory coal-dust cloud, that the linear relation between the *S*-scale optical density and the number of particles deposited on the paper still applied. They used horizontal $\frac{3}{16}$ in. papers aspiring at 1·25 cm³/min by means of constant-head water aspirators.

In order that filter-paper dust samples might, if desired, be evaluated underground immediately after they had been taken LLOYD (1950) made a small densitometer which fits on a miner's cap lamp.

5. UNDERGROUND TESTS OF SIZE-SELECTING HANDPUMP

5.1 *Sampling scheme*. The size-selecting handpump was compared with the short-period thermal precipitator at two coal-faces at different collieries for a total of 29 filling shifts extending over six months. The dust samples were taken in the return airway 50 yd from a longwall coal-face in order that the instruments should be sampling dust from a cloud of uniform concentration (HODKINSON, 1958).

The measurements, which covered the dustiest 4 hr of the shift, were grouped in 8 half-hour periods. During each period a pair of thermal precipitators took simultaneously two samples for 25 min, while a pair of handpumps each took simultaneously a group of successive samples. In order to obtain samples covering a wide range of density, these groups comprised 10 samples each of 8 pump strokes in the 1st and 5th half-hour periods of the shift, 5 samples of 16 strokes in the 2nd and 6th periods, 4 samples of 32 strokes in the 3rd and 7th periods and 3 samples of 64 strokes in the 4th and 8th periods. The mean stain-density of each group of handpump samples could then be compared with the particle number concentration given by the thermal precipitators in the same period. The samples taken by the size-selecting handpumps were duplicated, pump-stroke for pump-stroke, by a pair of P.R.U. Handpumps. Wiggins Teape 6615 esparto filter-paper was used for all the tests.

5.2 *Correlation between size-selecting handpump and thermal precipitator*. The pairs of simultaneous thermal-precipitator measurements showed the same scatter at both coalfaces, D_1 and W (Fig. 1(a)), and the random error of measurement is seen to be log-normal, i.e. proportional to the measured value of dust concentration. Regression analysis (JESSOP, 1952) gave the 95 per cent confidence limits of a single measurement as 59–170 per cent of the measured value or roughly ± 50 per cent of a central value. This is a large error, but not unknown in routine thermal-precipitator sampling underground (DAWES *et al.*, 1959; HODKINSON, 1960).

The random errors in the half-hour means of the size-selecting handpump samples were different at the two coal-faces (Fig. 1(c) and (e)), the confidence limits being 62–160 per cent at coal face D_1 and 78–130 per cent at W.

In Fig. 1(d) and (f) the mean stain density of the handpump samples for each half-hour period (both handpumps) is plotted against the mean number of 1–5 μ particles in a filter-paper sample, estimated from the mean of the corresponding pair of thermal precipitator measurements. (The slope of this graph gives the calibration factor relating stain-density to number of particles collected.) After allowing for the random error of the thermal-precipitator measurements, the handpump measurements are found to vary more or less linearly with the particle
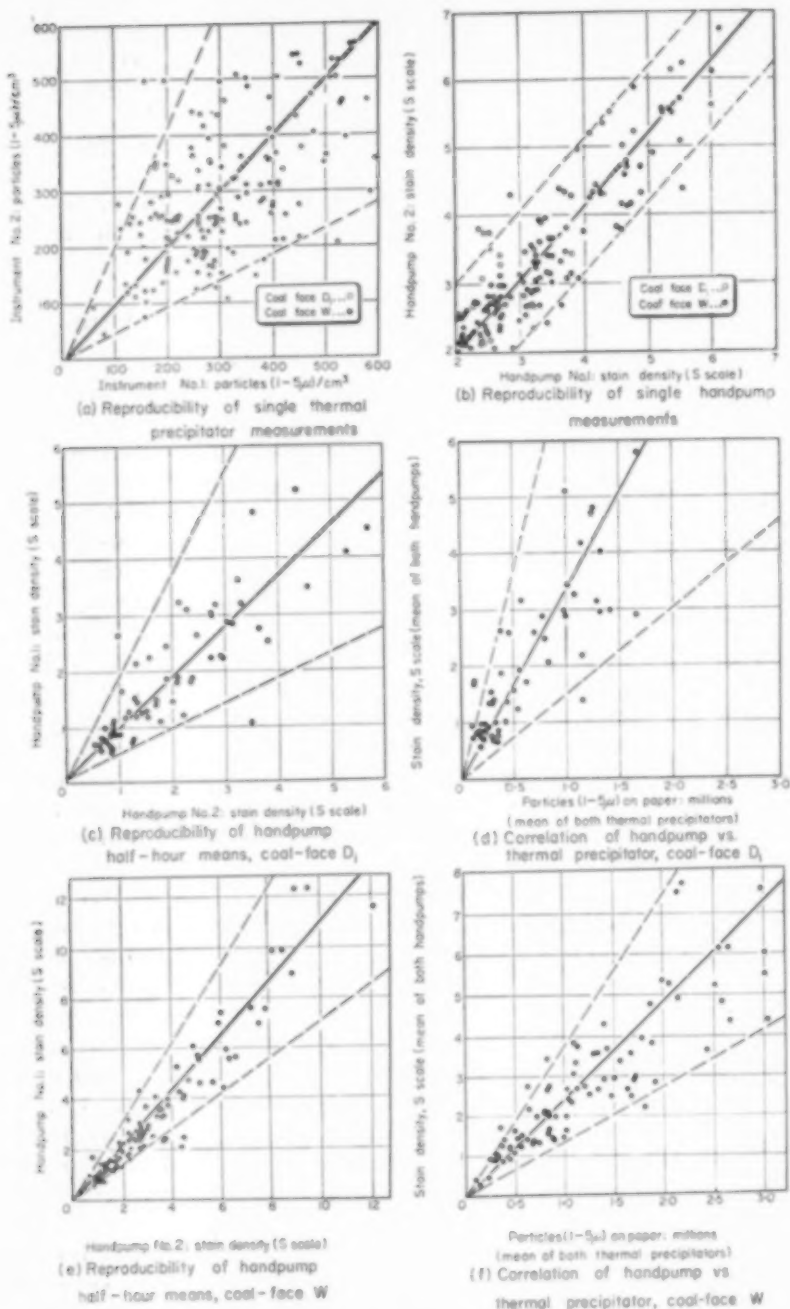
FIG. 1. Underground tests of size-selecting handpump against short-period thermal precipitator (section 5).

number concentration within confidence limits of 43–234 per cent at coal-face D_1' and within 65–155 per cent at W. These variations are very much greater than the random errors of the handpump measurement, given above, can account for.

There must therefore be large variations in the calibration factor k. Further regression analyses showed that on both coal-faces the variation in calibration factor within a single shift was equal to the variation in shift-mean calibration factor from one shift to another; the confidence limits were 57–174 per cent for coal-face D_1 and 75–133 per cent for W. Also, RAYBOULD (1958), using a P.R.U. handpump and Wiggins Teape paper found that the calibration factor varied considerably within and between a few shifts but its mean value had changed very little after an interval of several months. In the present tests the calibration factor did not appear to vary in any regular fashion with time during the shift, but showed a small increase with the number of pump-strokes used to take the sample. This will probably be eliminated by following the recommendations on handpump sampling made in section 5.3.

5.3 *Error of measurement with size-selecting handpump.* So far we have dealt with the handpump samples in half-hour groups because this was necessary for comparison with the thermal precipitator. We now wish to know the random error of measurement of a single handpump sample. These are plotted in Fig. 1(b); all samples with stain density $S \leqslant 2$ and all samples from 64 pump strokes have been rejected because their scatter is larger than the others. It is recommended that a sample should be taken with not more than 40 strokes, and since a density $S > 2$ cannot usually be obtained by 40 strokes in a dust concentration less than about 300 particles (1–5 μ) per cm^3 of air, it may sometimes be necessary to use a smaller filter-paper. The S value can be quadrupled without loss of accuracy by reducing the area of the paper to a quarter, i.e. from $\frac{3}{8}$ to $\frac{3}{16}$ in. diameter. The random error of measurement of such a sample is normal, not log-normal, with 95 per cent confidence limits $\pm 0.75S$. In good practice at least two samples are taken, and the error of their mean is thus $\pm 0.75/\sqrt{2}$ or $\pm 0.55S$, i.e. ± 25 per cent at $S = 2$ and less for $S > 2$.

An important function of the handpump is to compare dust concentrations at different times within the same shift. If we are taking the handpump measurements as an index of particle number concentration, then to the random error of measurement just deduced we must add the much larger within-shift variation in calibration factor. The result is that as an index of particle number concentration, the handpump measurement has 95 per cent confidence limits of 36–275 per cent. However there is no reason to believe that, during a given shift, the stain density is inferior to the particle number concentration as a *relative* index of the pneumoconiosis danger, in which case only the instrumental confidence limits of $\pm 0.5S$ apply, or better than ± 25 per cent. These are much narrower limits than applied to the reproducibility of thermal precipitator measurement (section 5.1). Similar confidence limits apply to comparisons based on the average handpump measurements on different shifts at the same face, but these are more conveniently made using the long-period sampler (section 6.3).

For the limited purpose of comparative measurements of dust concentration on a given shift, then, the handpump is preferable to the thermal precipitator. The

skill and labour required are much less and a far greater number of samples can be taken.

5.4 *Absolute value of calibration factor.* Table 1 brings together the mean values of the handpump calibration factor at these two and some other coal-faces: there is a ratio of about $3\frac{1}{2}$: 1 between the highest and lowest values. Theoretically, the calibration factor is given by $k = 0.096/D^2$ opaque particles (1 μ) per unit increment of stain density on the S-scale for a 0.71 cm² filter-paper (section 2). Unfortunately, the particle root-mean-square diameters (D) for the results in Table 1 are not available, since size-distribution counts were not made on the thermal precipitator samples. However, BURDEKIN and DAWES (1956, 1958) obtained size-distributions from thermal precipitators with and without inlet elutriators on a large number of coal-faces. They found that the number of 1–5 μ particles in unelutriated samples did not differ significantly from the total number larger than 1 μ in elutriated samples, and that the latter had an average root-mean-square diameter of 4.35 μ. Hence the average calibration factor for these coal-faces if the particles were opaque would be $0.096/(4.35 \times 10^{-4})^2 = 0.51$ million particles per unit stain-density. This is remarkably close to the average value 0.57 in Table 1.

TABLE 1. MEAN CALIBRATION FACTORS RELATING DUST CONCENTRATION IN PARTICLES PER CM² OF AIR TO OPTICAL DENSITY OF DUST DEPOSITS TAKEN ON $\frac{n}{8}$ IN. DIAMETER WIGGINS-TEAPE 6615 FILTER PAPER BY HANDPUMPS

(see sections 5.9, 5.10 and 5.12)

Coal-face (filling shifts)	Calibration factor millions of particles (1–5 μ) per unit S	
	Size-selecting Handpump	P.R.U. Handpump
Coal-face D_1	0.32	0.14
Coal-face W	0.44	0.22
Coal-face E	0.43	0.14
Coal-face G	0.80	0.20
Coal-face L	0.72	0.39
Coal-face D_2 (without dust suppression)	0.46	0.15
(S.M.R.E. 1954) (with dust suppression)	0.85	0.37
DAWES (1956)	—	0.55
Mean values	0.57	0.27
Predicted values for opaque particles	0.51	0.20–0.37

From the results in Table 2 and from laboratory tests on the S-scale it is found that the calibration factor of the Whatman no. 1 paper used by WATSON and HOUNAM (1948) for the P.R.U. handpump is about 50 per cent higher than for Wiggins Teape 6615 paper, owing to the greater non-uniformity of the dust deposit.

With Wiggins Teape paper, the absolute values of calibration factor for the long-period sampler are about 40 per cent less than for the size-selecting handpump. There is a ratio of about a thousand to one between the speeds at which air passes through the two instruments, but the penetration of particles through the paper was measured and in both instruments was only a few per cent in terms of optical density, which is far too small to account for so large a difference in calibration

factor. At the lower airspeed, however, the particles will penetrate further into the paper before impinging on the fibres, and, being distributed in depth instead of in a surface layer, they will overlap each other less and so absorb more light.

5.5 *Results with P.R.U. handpump.* The P.R.U. handpump measurements, which duplicated exactly those of the size-selecting handpump, were analysed in the same way. The random error of measurement of stain density was twice as great, but variation in the calibration factor relating stain density and particle number concentration was about the same as with the size-selecting handpump. It is unlikely, however, that its performance would be as good as the size-selecting handpump when sampling close to dust sources where the proportion of coarse, non-respirable particles is greater and more variable than in return airways. Also, the stroke timing and other operating conditions of the P.R.U. handpump depend more on the operator.

There is no elutriator on the P.R.U. handpump, hence non-respirable particles can reach the paper. Some loss of coarse particles occurs, even with the P.R.U. pump, because the nozzle is normally at right angles to the direction of the mine ventilation and the air velocity into the nozzle normally exceeds the ventilation velocity. The loss was estimated from filter-paper dust samples taken both iso-kinetically and with a P.R.U. pump in a wind tunnel, and appeared to be less than 10 per cent of the S value. The relevant root-mean-square diameter in the BURDEKIN and DAWES (1956) investigation (Section 5.4) is that of the particles larger than 1μ in the unelutriated thermal-precipitator samples, $D = 4 \cdot 75 \mu$. The ratio between the number of >1 and $1-5 \mu$ particles in this investigation was $1 \cdot 15$. The theoretical calibration factor is thus $k = 0 \cdot 096/1 \cdot 15 D^2 = 0 \cdot 084/(4 \cdot 75 \times 10^{-2})^2 = 0 \cdot 37 \times 10^6$ particles $(1-5 \mu)$ per unit stain density. An alternative body of data on the size-distribution of coal-mine thermal-precipitator samples is provided by ROACH (1958) where the root-mean-square diameter of the particles larger than 1μ was $6 \cdot 4 \mu$ and the ratio between the >1 and $1-5 \mu$ particles was $1 \cdot 2$, giving a theoretical calibration factor $0 \cdot 096/[1 \cdot 2(6 \cdot 4 \times 10^{-4})^2] = 0 \cdot 20 \times 10^6$ particles $(1-5 \mu)$ per unit strain density. The agreement between these predicted calibration factors of $0 \cdot 20$ and $0 \cdot 37$, and the observed range $0 \cdot 14-0 \cdot 55$ in Table 1, is therefore satisfactory.

6. UNDERGROUND TESTS OF LONG-PERIOD SAMPLER

6.1 *Unmodified sampler ($\frac{3}{8}$ in. paper, vertical elutriation).* A pair of long-period samplers operated continuously during the 4 hr of each shift during which sampling with the size-selecting handpump and thermal precipitator took place (section 5.1). Whatman No. 1 paper was used because both optical and air permeability measurements were made.

A comparison of the averages of the eight samples taken by each of the two thermal precipitators during each shift shows a log-normal error (Fig. 2(a)). The 95 per cent confidence limits for the shift-mean concentration determined by one instrument were 70–145 per cent. A comparison of the stain densities of the pairs of simultaneous filter-paper samples (Fig. 2(b)) gave a normal error of measurement with 95 per cent confidence limits of $\pm 0 \cdot 2$ units, or ± 15 per cent for the average reading $S = 1 \cdot 4$.

When the stain density and thermal precipitator measurements are correlated (Fig. 2(c) and (d)), and allowance is made for the random error in the latter, the variability of the optical density measurement with respect to the particle number concentration has 95 per cent confidence limits of 55–190 per cent at both D_1 and W coal-faces, values very similar to those obtained from averaging handpump samples over a shift (section 5.2). Nearly all this variation resides in the calibration factor.

(a) Reproducibility of short–period
thermal precipitator
(means of 8 samples)

(b) Reproducibility of long–period sampler

Correlations of long–period sampler with short–period thermal precipitator
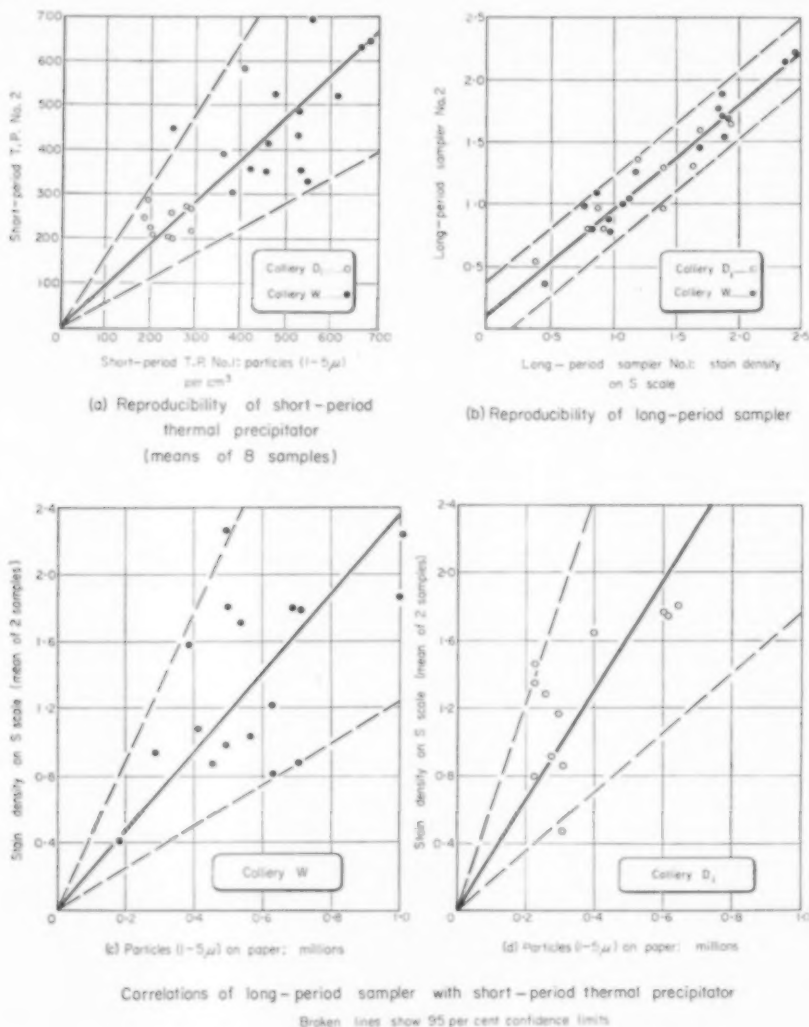Broken lines show 95 per cent confidence limits

Fig. 2. Underground tests (first series) of long-period filter-paper dust sampler (section 6.1).

Further tests of the long-period filter-paper sampler compared with the long-period thermal precipitator of Hamilton (1956) were made at 8 different collieries (WO, V, S, L_1, M, H, C and F) distributed between 7 coalfields in England and

Wales, sampling 10 coal-filling shifts at each colliery over a period of 6 months. The dust concentrations at these collieries were on the whole lower than D_1 and W, giving filter-paper samples whose density was too low for reliable analyses of the correlation with particle number to be made.

However, valuable information was obtained on the variation in mean calibration factor from one coal-face to another (Table 2). From the long-period thermal precipitator samples the relative proportions of coal and non-coal particles, and the root-mean-square diameters of the dusts, were also estimated. The mean calibration factors are seen to vary over a range of 4–1, and to be about half the theoretical values on the average. The expected correlation of calibration factor with particle size and proportion of transparent particles can be discerned, but only roughly. It must be mentioned however, that, in the size-distribution counts, particles above $6·25 \mu$ were not sized in detail, and their root-mean-square diameter has been estimated indirectly, as about 10μ, from the BURDEKIN and DAWES (1956) data. The air-permeability calibration factors showed similar variability.

6.2 *Modified sampler* ($\frac{3}{16}$ *in. paper, horizontal elutriation*). After the long-period filter-paper sampler had been modified to give a greater optical density by decreasing the area of the paper (section 4) it was further tested against the long-period thermal precipitator and the Hexhlet sampler (WRIGHT, 1954) at coal-faces B and D_3 for a total of 43 coal-filling shifts over a period of 6 months.

A pair of long-period thermal precipitators had been operated together at coal-faces C and F in the tests of section 6.1 (Fig. 3(a)), and the 95 per cent confidence limits for a single measurement were 83–121 per cent. A comparison of the stain-density measurements from the pair of modified long-period samplers (Fig. 3(b)) gave 95 confidence limits of $\pm 0·4S$ units of stain density. The modification to the sampler, though quadrupling the stain density, only doubles the absolute error, and so the percentage error is halved. In these tests, with an average stain density of 4, the average error was ± 10 per cent. Correlating the stain density with the thermal-precipitator measurements (Fig. 3(d) and (g)), and allowing for random error in the latter, the variability of stain density with respect to particle number concentration is found to have 95 per cent confidence limits of 55–190 per cent at coal-face B, and 65–155 per cent at D_3. This represents very little improvement on the results with the unmodified sampler (section 6.1).

At coal-face B it was possible to operate two Hexhlets together. A comparison of their measurements of the weight concentration of airborne respirable dust (Fig. 3(c)) suggests 95 per cent confidence limits of $\pm 0·6$ mg.m^{-3} or better than ± 15 per cent for most of the measurements in these tests. Each Hexhlet sample was taken over 3 shifts to give a weight of dust adequate for composition analysis. From the correlation of the Hexhlet and thermal-precipitator measurements (Fig. 3(e) and (h)) it was deduced that the random variation in measured gravimetric dust concentration, with respect to particle number concentration, was 55–190 per cent at coal-face B, and 65–155 per cent at coal face D_3. This variation is thought to arise from variations in size distribution to which the particle weight number correlation, depending on the cube of the particle diameter, is particularly sensitive.

It will be seen that the variability of the particle weight/number correlation is the same, at both coal-faces, as the variability of the stain density/particle number

o

correlation. The correlation between particle weight and stain density, however, is just as variable, as Fig. 3(f) and (i) show. It would appear, then, that the variability of the stain density/particle number correlation, i.e. of calibration factor k, cannot be accounted for by changes in the particle size distribution of the airborne dust. Neither can it be attributed to variations in dust composition, because mineral
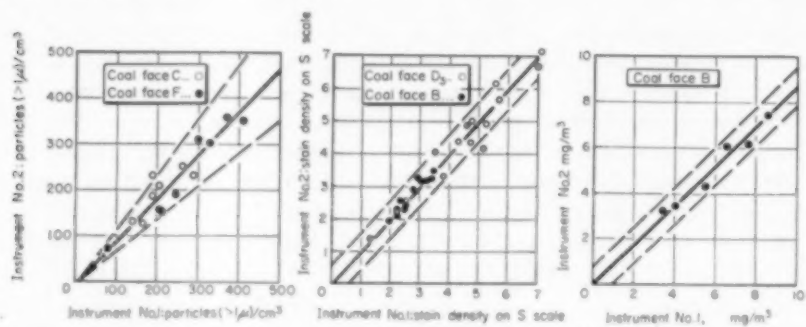
(a) Long-period thermal precipitator (b) Long-period filter-paper sampler (modified) (c) Hexhlet dust sampler

(a)-(c) Reproducibility of dust concentration measurement by long-period samplers
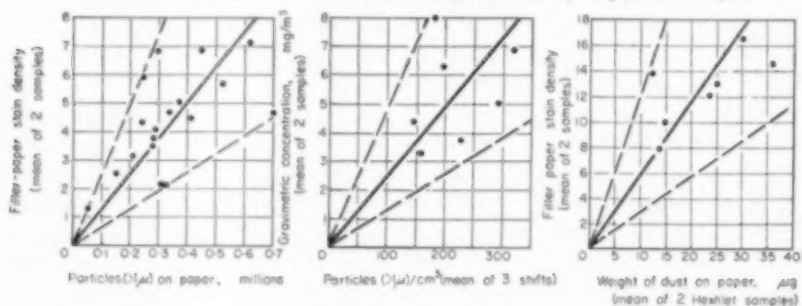
(d) Filter-paper sampler vs. long-period thermal precipitator   (e) Hexhlet vs. long period thermal precipitator   (f) Filter-paper sampler vs. Hexhlet

(d)-(f) Correlations between long-period samplers at coal-face B
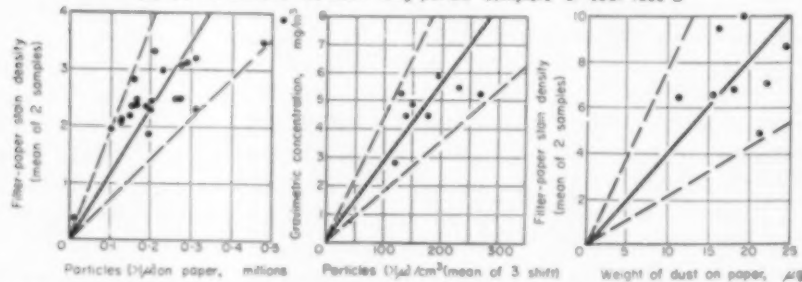
(g) Filter-paper sampler vs. long-period thermal precipitator   (h) Hexhlet vs. long-period thermal precipitator   (i) Filter-paper sampler vs. Hexhlet

(g)-(i) Correlations between long-period samplers at coal-face D

Broken lines show 95 per cent confidence limits

FIG. 3. Underground tests (second series) of modified long-period filter-paper dust sampler (section 6.3).

analyses of the Hexhlet samples showed them to have ash and quartz contents constant to within a few per cent throughout the tests at both coal-faces.

Laboratory tests on variation between different pieces of filter paper could not produce a variability with 95 per cent confidence limits of more than $\pm 0.1\,S$, i.e. less than 5 per cent in these underground tests.

The variation of stain density with wavelength of light, from 2000 to 10,000 Å, was measured for a few filter-paper dust-samples from both coal-faces. The density showed its highest values between 4000 and 6000 Å, i.e. in the visible spectrum normally used, so there is unlikely to be any reduction in variability by evaluation in the ultra-violet or infra-red regions.

The physical reason for a large part of the variation in the stain density particle number correlation with filter-paper samples of mine airborne dust is therefore not known.

DEGUELDRE (1958) also found, using the P.R.U. handpump with Whatman No. 1 paper to sample a wide range of working places and types of shift at a Belgian colliery, that the variations in calibration factor did not correlate with dust size distribution or composition. However, the mean calibration factors he obtained, ranging from 0.15 to 0.64 million particles (1–5 μ) per unit of stain density S agree remarkably well with the range of P.R.U. handpump factors given in Table 1.

6.3 *Error of measurement with long-period filter-paper sampler.* The instrumental error associated with a filter-paper dust sample taken by the unmodified sampler is $\pm 0.2\,S$ units of stain density, and by the modified sampler, $\pm 0.4\,S$ units. On average, the unmodified sampler will give a sample of minimum adequate density ($S > 1$) after 8 hr operation in a cloud of concentration about 150 particles (1–5 μ) per cm³; the modified sampler will do so in a concentration of about 40 particles per cm³.

The variation in stain density with respect to particle number concentration at a given coal-face has 95 per cent confidence limits of about 55–190 per cent. So, if the mean calibration factor for the face is known, the true value of particle number concentration is probably between 55 and 190 per cent of the estimate derived from the filter-paper sample. The same confidence limits apply when the stain density itself is taken as an index of particle number concentration, and when the shift average of size-selecting handpump samples are taken. However, as mentioned in section 5.3, for the simple purpose of comparison between shifts at a given coal-face, the stain density is probably as good a *relative* index of pneomuconiosis hazard as the particle number concentration. For this purpose the long-period filter-paper sampler gives less random error than the long-period thermal precipitator, with much less labour.

The results in Table 2 suggest that the mean calibration factor for one coal-face probably lies within 50 and 200 per cent of the mean value for all faces in the country. Compounding this with the variation between shifts at one coal-face, 55–190 per cent, gives overall 95 per cent confidence limits of 40–250 per cent. Thus, if the long-period sampler operates for a filling shift on any coal-face selected at random, and a national mean calibration factor is used to derive from the stain density an estimate of the particle number concentration, the true concentration probably lies within 40 and 250 per cent of that estimate.

Clearly the long-period filter-paper sampler, like the size-selecting handpump,

o*

is much inferior to the thermal precipitator for estimating particle number concentrations, and no better than the thermal precipitator for estimating particle weight concentrations. But for comparative measurements at a given coal-face, it gives greater reproducibility than the thermal precipitator.

TABLE 2. MEAN CALIBRATION FACTORS RELATING DUST CONCENTRATION IN PARTICLES (1–5 OR > 1 MICRON) PER CM³ OF AIR TO OPTICAL DENSITY OF DUST DEPOSITS TAKEN ON ⅞ IN. DIAMETER PAPER BY LONG-PERIOD FILTER-PAPER SAMPLER
(see section 6)

Test series	Coal-face (filling shift)	Per cent non-coal particles in microscope counts	Particle r.m.s. diameter in microscope counts, μ	Optical density calibration factor, millions of particles per unit S		
				Theoretical value $0.096/D^2$	Wiggins Teape 6615 paper	Whatman No. 1 paper
1st series (section 6.1)	D_1	—	—	—	—	0·31
	W	—	—	—	—	0·43
2nd series (section 6.2)	WO	31	3·0	1·07	0·46	0·60
	V	33	3·5	0·81	0·34	0·50
	S	38	3·1	1·0	0·16	0·35
	L_1	30	3·2	0·96	0·44	0·65
	M	32	4·3	0·53	0·28	0·57
	H	44	4·1	0·57	0·64	0·81
	C	16	4·9	0·40	0·21	0·32
	F	19	3·8	0·69	0·23	0·35
	Mean values			0·82	0·35	0·52
3rd series (section 6.2)	B				*	—
	D_3				*	—
Others	D_4				—	0·40
	L_2				—	0·62
	Mean values				0·35	0·50
	Range about mean				46–180%	62·162%

* Calibration factors obtained with ⅞ in. diameter papers, ×4.

7. CONCLUSIONS

Mathematical rigour is not claimed for the statistical techniques whereby the conclusions in this paper have been reached. Their use is justified chiefly by the fact that the confidence limits deduced from them fit the data when graphed. They are adequate, however, in estimating the magnitude of the large variations with which we have been dealing.

7.1 *The use of the filter-paper method of dust measurement.* It is concluded that the filter-paper stain density method, by which a dust sample of adequate density on Wiggins Teape 6615 paper is taken by means of a size-selecting handpump or

long-period sampler, and is interpreted on the *S*-scale of stain density by means of a "national" mean calibration factor, provides only a rough estimate of the dust concentration in terms of the number of respirable-size particles per cm^3 of air. This estimate of the shift-mean particle number concentration may be as much as 3 times too high or too low, compared with ± 20 per cent accuracy of the long-period thermal precipitator. Although the size-selecting handpump gives a greater accuracy of measurement than the P.R.U. handpump, there is not much reduction in the variability of the calibration factor relating stain density to particle number. Thus, for the purpose of deciding whether the general dust level on a coal-face complies with a specified maximum permissible particle number concentration the filter-paper method is of little value, except to distinguish between coal-faces with very low or very high dust-levels in the absence of skilled labour for microscope counting. Such was in fact the situation in the early years of the campaign against airborne dust in British mines, when the filter-paper method proved of great value.

Even today, however, when thermal precipitator sampling is possible on a large scale, the filter-paper method can perform a very valuable function: to compare dust concentrations in a particular working-place at different times, either within one shift by means of the handpump or from one shift to another by means of a long-period sampler. Although the calibration factor relating stain density to particle number shows large variations, the reproducibility of the stain density measurements in a given dust-cloud is better than the reproducibility of the corresponding particle number measurements by short- or long-period thermal precipitator; the skill required for sampling and evaluation is much less; and above all a much greater number of samples can be taken. Such comparative measurements are needed when studying the effect of different techniques of dust suppression, or when the dust concentration at a coal-face is known from thermal precipitator measurements to be too high and means must be tried to reduce it by an appropriate factor. The random variability of dust concentrations both within and between working shifts is so great that, unless a large number of samples can be taken, reliable conclusions cannot be drawn. The filter-paper method makes this possible.

7.2 *The physical basis of the filter-paper method.* On physical considerations, the *S*-scale stain density should be proportional to the total particle surface area if the particles absorb all light incident upon them, e.g. opaque coal-dust particles. The calibration factor relating stain density to number of deposited opaque particles will therefore vary with the particle size distribution, and the variation will be greater if some of the particles transmit some of the light falling on them. Although the range of variation in calibration factor observed in practice is limited, only slight correlation of these variations with differences in the size distribution or composition of the particles was observed; and under conditions of fairly constant composition and size distribution the calibration factor varied much more than instrument errors could account for.

Consequently it cannot be claimed that in practice the filter-paper method will necessarily correlate more closely with the weight or surface-area concentration of the dust than with the particle number concentration.

However, the national mean calibration factor deduced for these tests agrees satisfactorily with the mean value predicted from the knowledge of the average size distribution of coal-face dust clouds.

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OBITUARY

Sir Ernest Rock Carling, LL.D., M.B., F.R.C.P., F.R.C.S., F.F.R.

THE death of Sir Ernest Rock Carling on July 15th at the age of eighty-three is a great personal loss to a wide circle of friends and colleagues in many branches of medicine. Not only is it because he had a diversity of interests and experience which have been covered by few men in the profession, but because he was still active and served in a variety of important posts with a wisdom and vigour which appeared even to increase as the years went by.

His surgical career is identified with the Westminster Hospital, where he was a brilliant undergraduate and gold medallist. He joined the staff in 1906 and served the hospital with great distinction until his retirement in 1942. It was not only his operative skill and judgment as a surgeon and his widely sought clinical opinion and advice as senior surgeon that made him such an important figure in the history of the Westminster, but he also gave outstanding service in many fields other than surgery, and his leadership played a great part in placing his hospital in the position of eminence which it holds today.

He became Dean of the Medical School at a critical period when the hospital and school on its old site off Parliament Square was in need of reconstruction, and he carried through the project, giving meticulous personal attention to every detail until the beautiful new Westminster was completed on its present site in Horseferry Road. He recognized at an early stage the part which irradiation was destined to play in the treatment of cancer, and, in particular, the necessity for close co-operation between surgery and the newly developing science. It was his vision and energy that inspired Westminster first to acquire radium and later to start its radium annexe, and to undertake some of the first developments of tele-radium in this country.

From the early 1920's Rock Carling was interested in the training of radio-therapists. He was Chairman of the Special Advisory Board in Radiology of the University of London which was responsible for the University's Diploma in Medical Radiology, and he was Vice-Chairman of the National Radium Com-mission. It was largely as a result of the Commission's policy that radiotherapy developed as a specialty distinct from diagnostic radiology. His great interest in radiology and the help that he gave were recognized by his election to the Honorary Fellowship of the Faculty of Radiologists in 1940.

On his retirement from the active staff of Westminster in 1942, Rock Carling began a second career which might be considered even more fruitful than his first. He had already served as a surgical dresser in the South African War and in the R.A.M.C. in the First World War, and he now found himself fully involved again as an adviser to the Emergency Medical Service and to the Ministry of Home Security. These advisory appointments multiplied, and included the Ministry of Pensions, the Ministry of Health and the Home Office.

In the development of radiotherapy and in radiological protection, his services

were particularly in demand. Having already served on the Medical Research Council he became Chairman of its committee concerned with the biological application of nuclear physics and a member of its Committee on Protection against Ionising Radiations. He was then elected Chairman of the International Commission on Radiological Protection and he served on the Radioactive Substances Advisory Committee, where he was responsible for various panels which produced the codes of practice designed to ensure safe usage of radioactive materials. He was Chairman of the Ministry of Health Standing Cancer and Radiotherapy Advisory Committee and a member of the Ministry of Labour's panel on radiological protection.

Radiological matters were however only one part of his interests. He was President of the Medical Protection Society, Treasurer of the Society for the Relief of Widows and Orphans of Medical Men, and served on the Council of the Royal Medical Benevolent Fund. As Chairman of the Medical Advisory Committee and a trustee of the Nuffield Provincial Hospitals Trust he developed considerable interests in Industrial Medicine and Occupational Hygiene which he did much to encourage. Civil Defence and the furtherance of the peaceful uses of ionizing radiations were perhaps Rock Carling's most intense and abiding interests in his later years, and no course of instruction in these subjects, in whatever part of the country, could be complete without his characteristic common sense contribution.

He was knighted in 1944, elected to the Fellowship of the Royal College of Physicians in 1945, and to Honorary Fellowship of the Royal Society of Medicine in 1949. In 1952 the honorary degree of LL.D. of Queen's University Belfast, was conferred on him for his services to Northern Ireland.

In many fields his contributions were unique, and he has left behind a host of colleagues who remember with gratitude his ever ready help and advice and his willingness always to shoulder further duties and responsibilities to the utmost of his capacity.

B. W. WINDEYER

NOTE

American Careers in Industrial Hygiene

THE Atomic Energy Commission sponsors fellowships which will train personnel for work in industrial hygiene in order to alleviate the manpower shortage in this field, a major concern to all atomic energy industry.

Applicants must have a bachelor's degree with a major in physics, chemistry or engineering. Mathematics through calculus is required and some college biology desirable. Academic training beyond the bachelor's degree or industrial experience is also desirable. Fellows must be United States citizens, under 35 years of age, and acceptable for graduate work at the university to which they are assigned. Appointments are not effective until the applicant is granted fellowship clearance by the Atomic Energy Commission in accordance with existing law.

The tenure of the fellowship is for the academic year, beginning with the fall term. Fellows will receive training in industrial hygiene at Harvard University, the University of Cincinnati, the University of Michigan, or the University of Pittsburgh. Applicants may indicate their choice of institution, and when possible assignment will be made accordingly; however, the Institute cannot guarantee choice of assignments.

The basic stipend for the academic year is $2500 with additional family allowances.

Further information may be obtained from the Industrial Hygiene Fellowship Office, Institute of Nuclear Studies, Oak Ridge, Tennessee.

NEWS

A New Academic Course in Occupational Hygiene

WITH the aid of a grant of £20,000 from the Nuffield Foundation the London School of Hygiene and Tropical Medicine is offering a new course in occupational hygiene. It will be whole time for nine months starting on 2nd October, 1961. The course is open to graduates whose undergraduate studies, or previous experience, provide a suitable preliminary training. In general, graduates in physics, chemistry, engineering, medicine or allied subjects would have the necessary background. In special circumstances non-graduates would be accepted.

The University of London is being asked to establish an academic diploma in this subject. If this is not done there will be an alternative method of recognizing proficiency.

The course will include systematic instruction in:

(1) *The general background to occupational health*—outline of industrial law, functions of management, trades unions and industrial health services.

(2) *Occupational health engineering*—the measurement and control of chemical, physical and biological hazards of work.

(3) *Epidemiology and statistics*—the purpose of epidemiology used in field and laboratory studies.

(4) *Physiology, occupational toxicology and disease*—elementary principles of physiology and toxicology and descriptions of occupational injuries and diseases.

(5) *Information and reports*—sources of information and uses of libraries, the presentation of technical reports and scientific papers.

Practical instruction will be a major feature of the course and will comprise demonstrations, exercises in environmental measurements and visits to factories and other places and institutions.

The grant from the Nuffield Foundation will be used to equip a teaching laboratory and to offer a training fellowship for a graduate to take this course with the prospect of appointment to the staff of the Department of Occupational Health at the London School of Hygiene and Tropical Medicine at the end of the course.

Further particulars on qualifications for admission and fees may be obtained from the Registrar of the London School of Hygiene and Tropical Medicine, London, W.C.1.

ERRATUM

C. H. BEDWELL, The problems associated with fine and other visually difficult concentrated tasks in industry. *Ann. Occup. Hyg. 3*, 84–93 (1961).

In the plates facing p. 90 the half-tone Figs. 10 and 11 should be interchanged, i.e. the left-hand photograph is Fig. 11 and the right-hand photograph is Fig. 10.

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THE DIURNAL VARIATION OF WARMTH AND DISCOMFORT IN SOME BUILDINGS IN SINGAPORE*

C. G. WEBB

(*Read at a joint meeting of the B.O.H.S. and the Ergonomics Research Society, held in London on 24 June* 1960)

(*Received* 29 *November* 1960)

Abstract—The physical aspects of the design of Malayan buildings are outlined, and illustrated with drawings and photographs. The diurnal variations of various physical factors affecting thermal comfort, averaged over 14 buildings in Singapore, are described in detail and some of their implications are discussed. The variations also of sweating, of a subjective thermal assessment, of thermal discomfort, and of subjective warmth as measured by the Equatorial Comfort Index are described and discussed.

The main points of interest are the prevalence of discomfort and sweating, the subjective warmth of the evenings and the cold of the early morning hours, the lightness of indoor air movement in the absence of fans, and the insignificance of temperature differences between the building fabric and the air.

MALAYAN BUILDINGS

THE buildings of Malaya (of which Singapore is geographically a part) may possibly be unfamiliar, at least in their physical aspects, to some; and I propose to introduce my talk with a brief description of the principal physical features of typical Malayan houses. The Malayan house is of a well-defined type, calculated to make the best of what is a fairly average example of an equatorial coastal climate. The house is also, thermally speaking, rather simple in comparison with the typical cool-climate house; a fact which makes my present task a relatively easy one.

First of all, Malayan houses are unheated. There is no fire, or hearth, or chimney. Cooking is done outside the house whenever possible. Next, they are well shaded from the sun, and are often orientated so as to minimize the solar heat load. Again, they are exceptionally well ventilated, having large unglazed windows and other ventilation openings, being raised above ground level, and often having open-work material for some at least of their walls. In traditional Malay houses the floors also may be only loosely boarded, the roof very lightly thatched, and there may be no ceiling. The whole house is, in fact, sievelike in construction. The rate of air change must be very high in such buildings, ten or more times greater than the rates we are used to in England. Finally, the thermal capacity of Malayan buildings is relatively low.

The thermal function of the Malayan house is, on the other hand, more rather than less complex than that of its cool climate counterpart, which has merely to resist the outflow of heat supplied by a stove of some kind. In contrast with this, the Malayan house has to resist the entry of solar and other heat, and at the same time to encourage the outflow of metabolic heat and moisture. Accordingly it is carefully orientated and shaded from the sun, as well as being extremely well ventilated, as I have said. There are other types of tropical house performing the same task in other ways, but they are not common in Malaya.

Figure 1 (HILTON, 1956) is a drawing of the elevation of a basic Malay house, and Fig. 2 (*ibid.*) is a section of the same house. The large, lightly thatched roof will be

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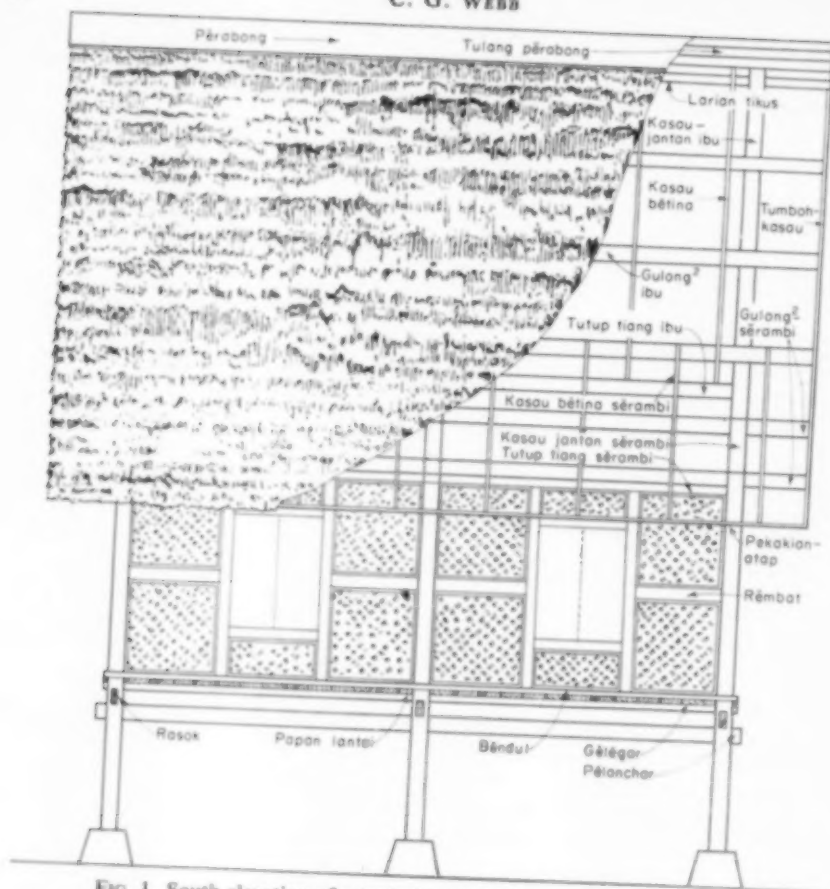
FIG. 1. South elevation of a typical small Malay house (Hilton 1956).

noticed, and the walls of plaited material. The house is raised several feet above the ground, on piles. The part of the house forming the right-hand third in Fig. 2 would often be an open verandah; and cooking would be done outside the main part of the house at least.

Figure 3 (ATKINSON, 1952) is a photograph of a larger house of the same type, built of more lasting, and more expensive, materials; and Fig. 4 (*ibid.*) is one of a Malay school in concrete and tile. Both buildings exhibit the design features that I have described.

The fourteen buildings which were examined for the present purpose were selected to cover all types present in Malaya, with some emphasis on the less satisfactory. Two buildings (and a motor vehicle which was also examined) had metal roofs, although metal roofs are not at all common in Malaya.

The observations were made in 1949–50. In all, about 450 sets of observations were made at half-hourly intervals, and were spread over a period of some months from April to September inclusive. Each set contained ten or a dozen statements. The annual component was ignored, being only about a fifth of the diurnal component, and to some extent self-cancelling. The data furnish a conspectus of the

Fig. 3. Traditional Malay house near Malacca (Atkinson 1952).

Fig. 4. A Malay school near Kuala Lumpur (Atkinson 1952).
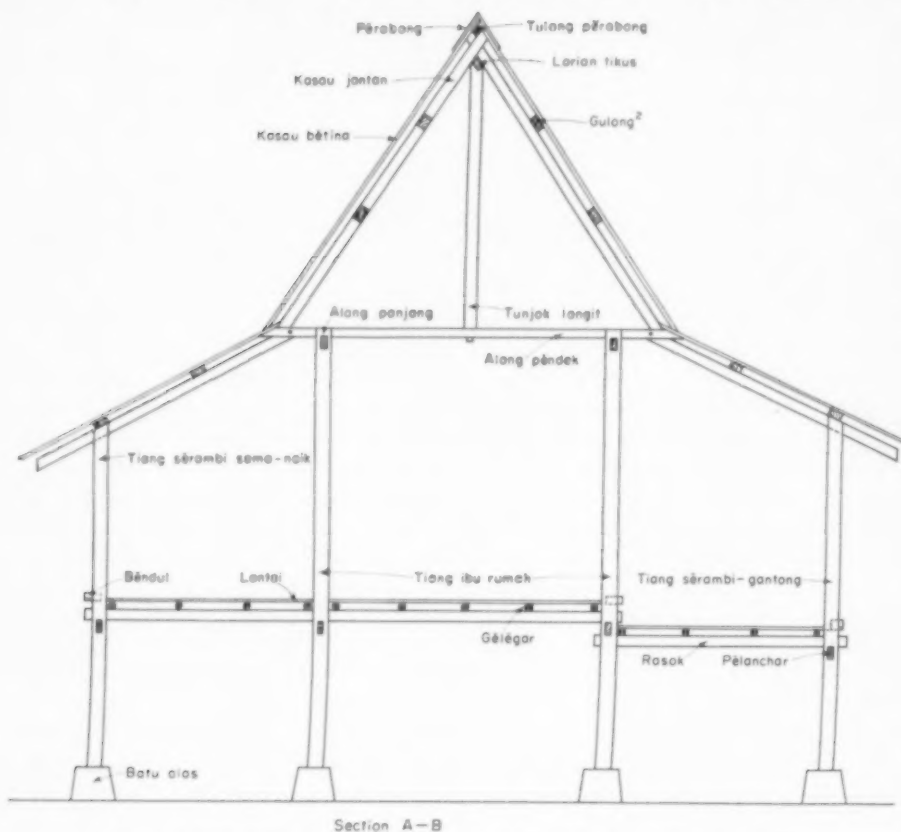
Section A—B

FIG. 2. North–South section of a typical small Malay house (Hilton 1956).
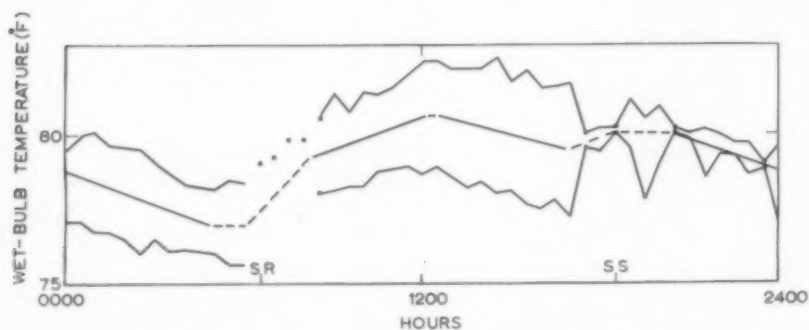
FIG. 5. Diurnal variation of the *wet-bulb temperature*, averaged for 14 buildings in Singapore. Straight lines have been fitted to the data wherever possible, i.e. wherever the curvature was insignificant. Intermediately, a broken curve indicates the estimated average. The limits of the standard deviation are shown by zig-zag lines above and below the graph. The range of observations was about four times the standard deviation.

indoor climates of Singapore at that period. It is possible that conditions may since have changed, and that the change has been for the better.

THE INDOOR CLIMATE AND ITS DIURNAL VARIATION

1. *The wet-bulb temperature*

The indoor climates of Malaya are of course very warm by our standards. The wet-bulb temperature reaches well into the eighties on the Fahrenheit scale, and in this range it is well known that wet-bulb readings are often the most useful single climatic measurement. It is the more unfortunate that observers in equatorial climates often work out humidities and other indices, and fail to mention the wet-bulb temperature which was the point of departure for their calculations. Suppose we do otherwise, and begin with the wet-bulb reading.

Figure 5 shows the diurnal variation of the wet-bulb temperature averaged over the 14 buildings. Straight lines have been fitted to the data wherever possible, i.e. wherever curvature is insignificant and the observations are sufficiently numerous. Intermediately a broken curve indicates the estimated average. The limits of the standard deviation are shown by the zig-zag lines above and below the graph, the range of the observations at each interval being about four times the standard deviation. The graph, taken as a first rough sketch of the daily variation of subjective warmth, has some interesting and slightly unexpected features. The principal peak occurs immediately at noon (mean noon was at 12.35 Malayan Time) and there is a second peak at sunset. The dip between is also of appreciable significance, since it is supported by the trend of the numerous afternoon values and those of the night. During the night there is a long decline which terminates just before sunrise; and is followed by a sharp rise, to what might be considered a typical daytime value of about 80 °F at 9 a.m. The average value at 6 a.m. was 76 °F. The complete range of observed values of the wet-bulb temperature was from 75 to 86 °F.

2. *The dry-bulb temperature*

The diurnal variation of the ordinary dry-bulb air temperature, illustrated in Fig. 6, was rather simpler than that of the wet-bulb temperature. The daytime peak occurred in mid-afternoon, and was fairly sharp. There was no second peak in the evening. Again the long decline during the night was terminated just before sunrise, and the initial rise was fairly steep. The range of observations of the air temperature was from 78 to 92 °F.

As a measure of the radiation flux, readings were taken also with a 6-in. diameter globe thermometer. In spite of the low values of the air velocity, which will be discussed later, it was found that the difference between the readings of the ordinary dry-bulb and the globe thermometer was quite small. This was especially so when the roof was of thatch or tile, but even with a metal roof it was much less than had been expected. Figure 7 shows the diurnal variation of the difference for the buildings with non-metallic roofs. Clearly very few differences exceeded 1 °F, and the average difference at any time was at most one or two tenths of a degree. Figure 8 shows all the values of the difference which were obtained, data from buildings with metal roofs being included (although in practice such buildings are rare). It will be seen that the largest value of the difference was +7 °F, the globe thermometer reading being the higher. The largest negative value was −4·2 °F. By night the

average difference was almost zero, the standard deviation being less than 1 °F. The maximum average difference by day was +0·6 °F, with a standard deviation of about 1 °F.

The implication of this result is that the fabrics of the buildings examined were at the same temperature as the air which ventilated them, to a sufficiently close approximation for the purpose of discussing thermal discomfort. Exceptions were few and of no great significance, and were almost confined to buildings with metal roofs. It seems likely that this is a characteristic of buildings of this type, i.e. those which are well shaded from the sun, unheated, extremely well ventilated, and of low thermal capacity.
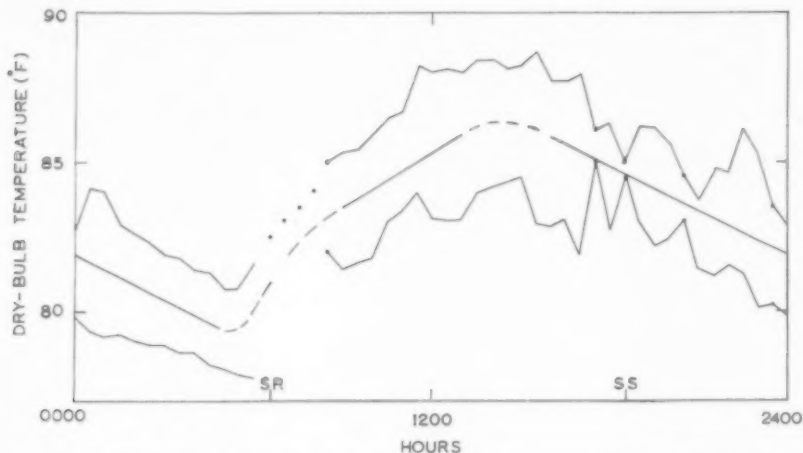
Fig. 6. Diurnal variation of the *dry-bulb temperature*, averaged for 14 buildings in Singapore.
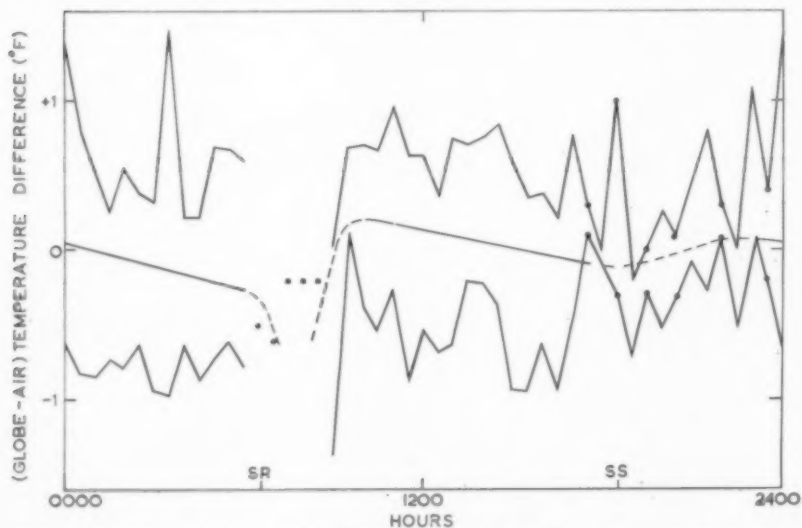
Fig. 7. Diurnal variation of the *difference between the globe thermometer and the dry-bulb thermometer readings* averaged for nine buildings, those with metal roofs or other detrimental features being excluded.
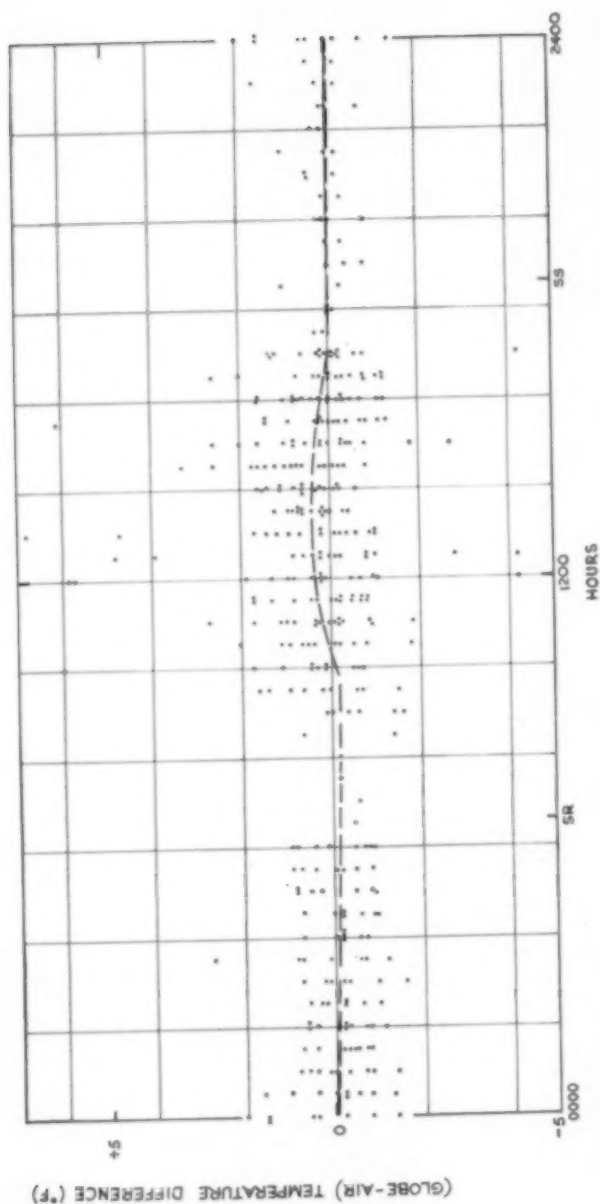
Fig. 8. Diurnal variation of the *difference between the globe thermometer and the dry-bulb thermometer readings*, the individual readings being shown, for all 14 buildings.

3. *Humidity*

As a by-product it may be of interest to consider the relative humidity, whose diurnal variation is shown in Fig. 9. The relative humidity was at all times high, the
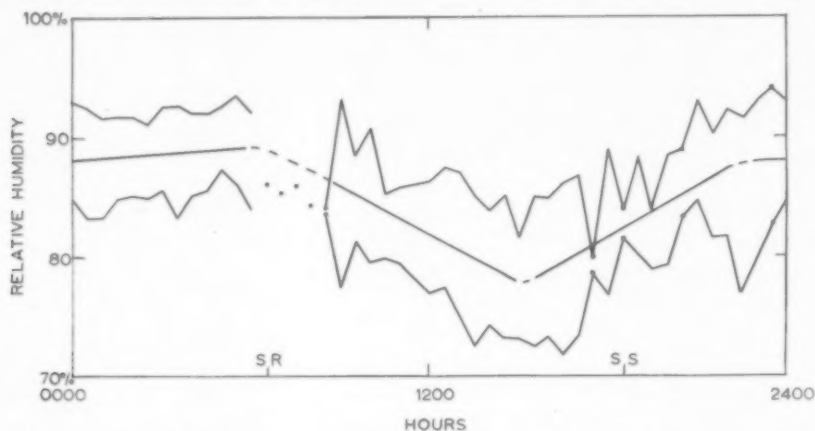
FIG. 9. Diurnal variation of the *relative humidity*, averaged for 14 buildings in Singapore.

observed values ranging from 60 to 100 per cent. It was least in the mid-afternoon when an average of 80 per cent was obtained, and was fairly steady from 10 p.m. to sunrise at an average of 89 per cent. It is interesting that saturation does not appear to occur indoors even at night, when it is normal outdoors in this very humid climate. The absolute humidity, expressed as the water vapour pressure in millimetres of mercury, varied from an average minimum of 23 mm at sunrise, to a maximum of 25·5 mm in the early afternoon. The range of observations was from 22 to 30 mm.

4. *Air movement*

The air movement also was investigated, using kata thermometers. Winds are for the most part of local origin in Singapore, and tend to be very light. Since buildings are so open in design, and in the cases examined were without fans or punkahs, it might be thought that the indoor velocity would be always closely related to the outdoor velocity, but the evidence is otherwise.

The diurnal variation is shown in Fig. 10, where the square root of the velocity is
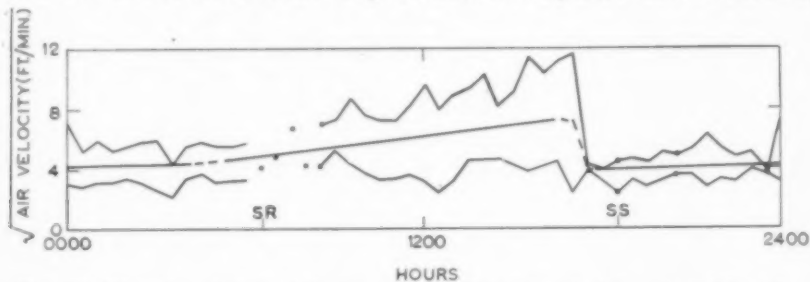
FIG. 10. Diurnal variation of the *square root of the air velocity*, averaged for 14 buildings in Singapore.

plotted, as more representative of the effect of this variable on the comfort of the
occupants. It will be noticed that the velocity is almost constant from sunset, or a
little earlier, until sunrise at 16 ft/min; the standard deviation of the square root
being about 1 (ft/min)$^{\frac{1}{2}}$. During the day the square root rises steadily to 7 (ft/min)$^{\frac{1}{2}}$
at 5 p.m., when a sudden drop occurs to the night-time value of 4. The standard
deviation also rises, to about 3 (ft/min)$^{\frac{1}{2}}$ at 5 p.m.

Although no closely comparable outdoor values were available, the meteorological
data for Singapore, and the data for light air movements obtained by Ho (1952),
indicate a different pattern for the outdoor velocity, which has a maximum almost
at noon and declines to very low values indeed between midnight and sunrise. There
is some evidence that after midnight the outdoor values are lower than those indoors.
The powerful "sumatra" squalls of the early morning in Singapore are it seems too
brief and irregular appreciably to affect the average.

THERMAL DISCOMFORT AND ITS DIURNAL VARIATION

1. *Sweating*

The 14 observers, all of whom were fully acclimatized, were asked to report on
sweating, and their comments were graded as nil, slight, sweating (without further
qualification), and profuse. The percentage of comments indicating profuse sweating,
and the percentage indicating any sweating at all, varied as shown in Fig. 11.

The main period during which people sweat is the mid-afternoon, with the late
morning second in importance, and, surprisingly, the night a close third. There was
no sweating from 3 to 8 a.m.; and very little at sunset.
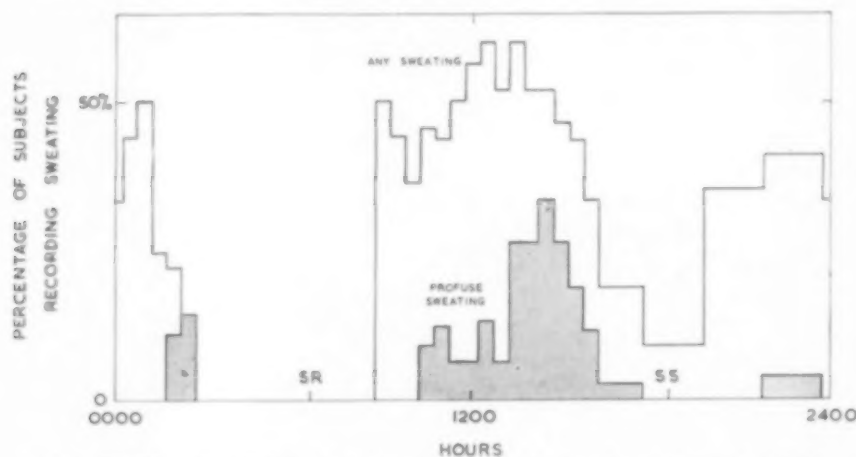
Fig. 11. Diurnal variation of the *percentage of subjects who were sweating*. The
outline shows the total percentage who were sweating; and the shaded areas those
who were sweating profusely.

2. *The average thermal assessment*

The climate was assessed subjectively each time, just before it was measured. The
subjective scale was as in Table 1.

TABLE 1

Subjective assessment					Scale number
Excessively cold	..	..	..	..	0
Cold	..	..	..	..	..	1
Cool	..	..	..	..	..	..	2
Comfortably cool	..	..	..	..	3
Comfortable and neither cool nor warm	..				4
Comfortably warm	..	..	..	..	5
Warm	..	..	..	..	..	6
Hot	..	..	..	..	..	..	7
Excessively hot	..	..	..	..	8
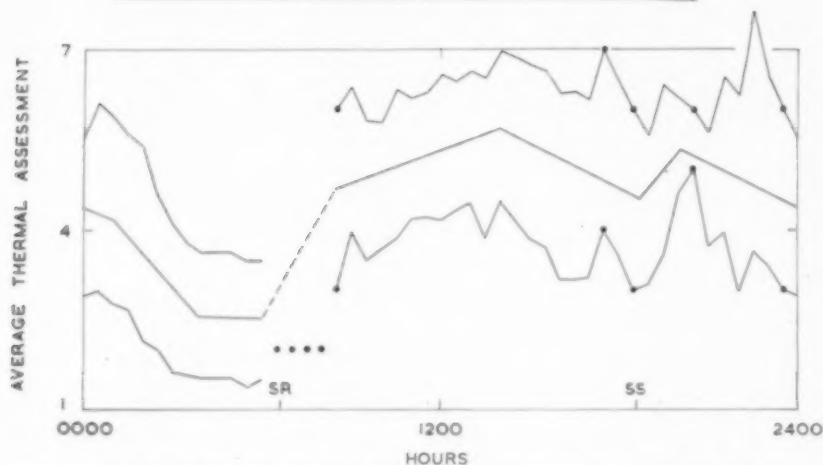
FIG. 12. Diurnal variation of the *subjective thermal assessment* averaged for 14 subjects. The thermal assessment was on the scale given in Table 1.

None of the observed climates was rated as excessively cold and only one as excessively hot, so that in use the scale was rather similar to Dr. Bedford's 7-point scale (BEDFORD 1936).

The assessments were averaged at each half-hour and the diurnal variation of the average is shown in Fig. 12. The second peak in the evening is interesting; but of course the usefulness of the average is severely limited by the character of the scale, and it is not proposed to dwell on this graph.

3. *Thermal discomfort*

More revealing is the percentage of assessments which indicated thermal discomfort. For this purpose it is supposed that assessments 0, 1 and 2 on the above scale indicated discomfort due to cold; assessments 3, 4 and 5 indicated the absence of discomfort; assessments 6, 7 and 8 the presence of discomfort due to warmth.

The diurnal variation of the discomfort percentages is shown in Fig. 13. Apart from the brief period round 4 to 5 p.m., discomfort due to cold was confined to the period between midnight and 7 a.m. Discomfort due to warmth was common at all times except from 2 to 8 a.m. At almost any time the total discomfort, due to either cause, totalled nearly 50 per cent, except possibly between 7 and 8 a.m. This is high, though perhaps not surprisingly so. If it is typical of the populations of

equatorial countries there appears to be a real need for enquiry into methods of reducing thermal discomfort.
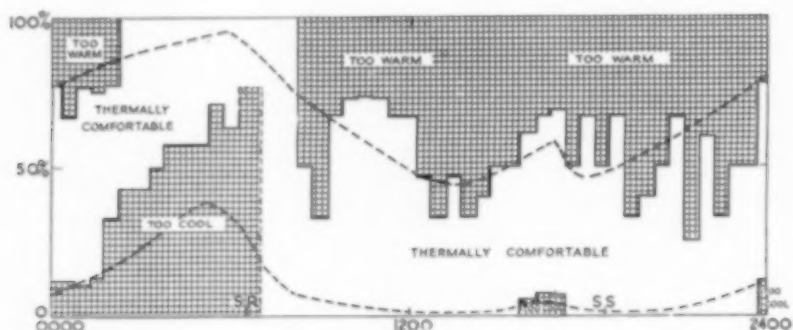
Fig. 13. Diurnal variation of the *percentages of subjects who were too cool, comfortable, and too warm*. During the first hour after sunrise the percentages were indefinite. The broken graphs show estimated percentages derived from the average values of the Equatorial Comfort Index.

4. *Subjective warmth*

Previous papers (Webb 1959 and 1960) have shown that it is possible to simplify the description of warm humid (and other) climates by assessing them in terms of a climatic index which correlates with subjective or physiological variables. The Effective Temperature was such an index, and the Equatorial Comfort Index is another which has been tested successfully on the present data. The Equatorial Comfort Index nomogram is shown in Fig. 14. It gives the temperature of still air saturated with moisture, which is physiologically equivalent to the climate under consideration in its effects on fully acclimatized males, lightly active and dressed to suit themselves, in rooms the walls of which are at the same temperature as the air.

The diurnal variation of the Equatorial Comfort Index is shown in Fig. 15. It will be seen that the ECI was almost constant from 11.30 a.m. to 6.30 p.m. at an average value of $81 \cdot 3$ °F ECI, apart from a slight dip at 4 p.m. Thereafter there was a long decline to 77 °F ECI at 5.30 a.m., and a rise, probably rapid at first, to the daytime value.

The similarity to the wet-bulb graph will be noticed (cf. Fig. 5). In fact the indoor climates of Malaya are such that in most cases the two are not very different; and, since the differences are fairly random, the averages are almost identical. Wet-bulb data are therefore likely to be quite useful as a first estimate of the value of the Equatorial Comfort Index in a warm, humid climate. Unfortunately crude wet-bulb data are rarely published, although their value for the subjective description of warm climates has been known for at least half a century. Figure 16 (BROOKS 1950) shows world wet-bulb isotherms for July, from which one can delineate the warm regions close to the equator, which are enclosed by the 75 °F wet-bulb isotherm; and the very warm areas in Northern India and the Persian Gulf enclosed by the 80 °F isotherm. More detailed maps exist for India (DORAISWAMY IYER 1944) and U.S.A. (VISCHER 1954).
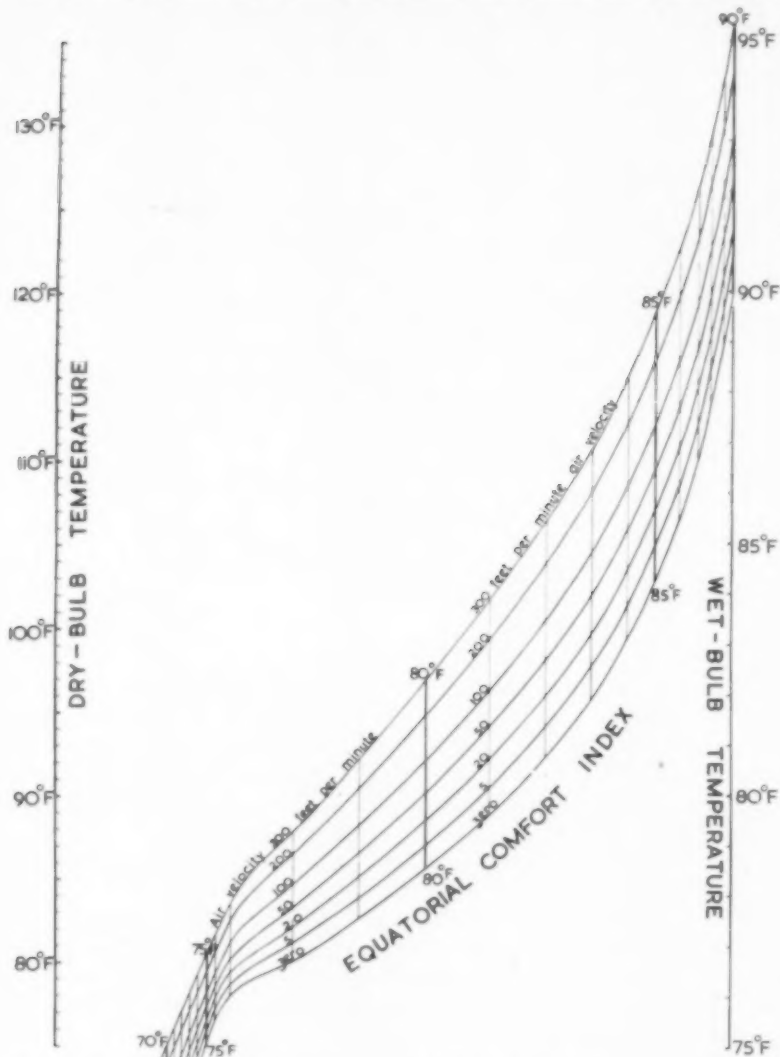
Fig. 14. Equatorial Comfort Index nomogram. The index is the temperature of still air, saturated with moisture, which is, for fully acclimatized adult males who are lightly active under ordinary living conditions, physiologically equivalent to the climate under consideration. To use the nomogram lay a thread or ruler across it from a point on the right-hand scale corresponding to the wet-bulb temperature to one on the left corresponding to the dry-bulb temperature. Select the curve corresponding to the air velocity and observe the intersection between the ruler and the curve. The intersection, in relation to the short vertical lines, shows the value of the Equatorial Comfort Index in degrees Fahrenheit.

In a previous paper a comfort graph was given for the present Singapore subjects, which indicates an optimum value of the Equatorial Comfort Index close to 78 °F. The comfort graph is here reprinted (Fig. 17). The average value is below the optimum only from 3 to 7 a.m.

C. G. WEBB
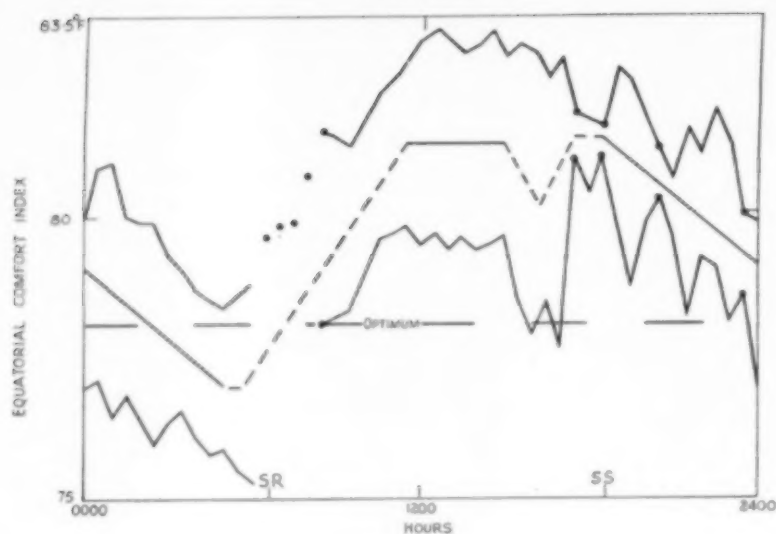
FIG. 15. Diurnal variation of the *Equatorial Comfort Index*, averaged for 14 buildings in Singapore.

CONCLUSION

The main points of interest in the diurnal variations which have been shown and described are the continuous high incidence of thermal discomfort, running at about 50 per cent for almost the whole 24 hr; the prevalence of sweating by day, and even at night; the occurrence of a considerable amount of discomfort due to cold in the early hours of the morning; and the subjective warmth and discomfort of the evenings, which is associated with an absence of air movement. These features are in accordance with the values of the Equatorial Comfort Index, and the comfort graph for the subjects concerned.

The Equatorial Comfort Index nomogram reflects the importance of the cooling effect of slight air movements; and in this connexion the continual, though slight, movement of the air at night is interesting. It seems possible that in the absence of wind and of fans this is caused by the occupants, directly and through the stack effect of their metabolic heat.

The absence of any material difference between the air temperature and the temperature of the inner surfaces of the fabric of the building appears to be characteristic of this type of building. The incomplete saturation of the indoor air at night also may be characteristic.

It has been my purpose to describe the rather simple but characteristic indoor climates of a typical equatorial city. As comment it might be added that in order to reduce the high incidence of thermal discomfort, in other words to extend the periods during which the indoor climate is satisfactory, to the whole 24 hr if possible, it is necessary to provide coolness during the afternoon and evening, and also to provide warmth during the latter part of the night. There is little doubt that warmth at night is the more important for many people, even in Singapore, and this should be a prime consideration in the design of bedrooms. On the other hand,
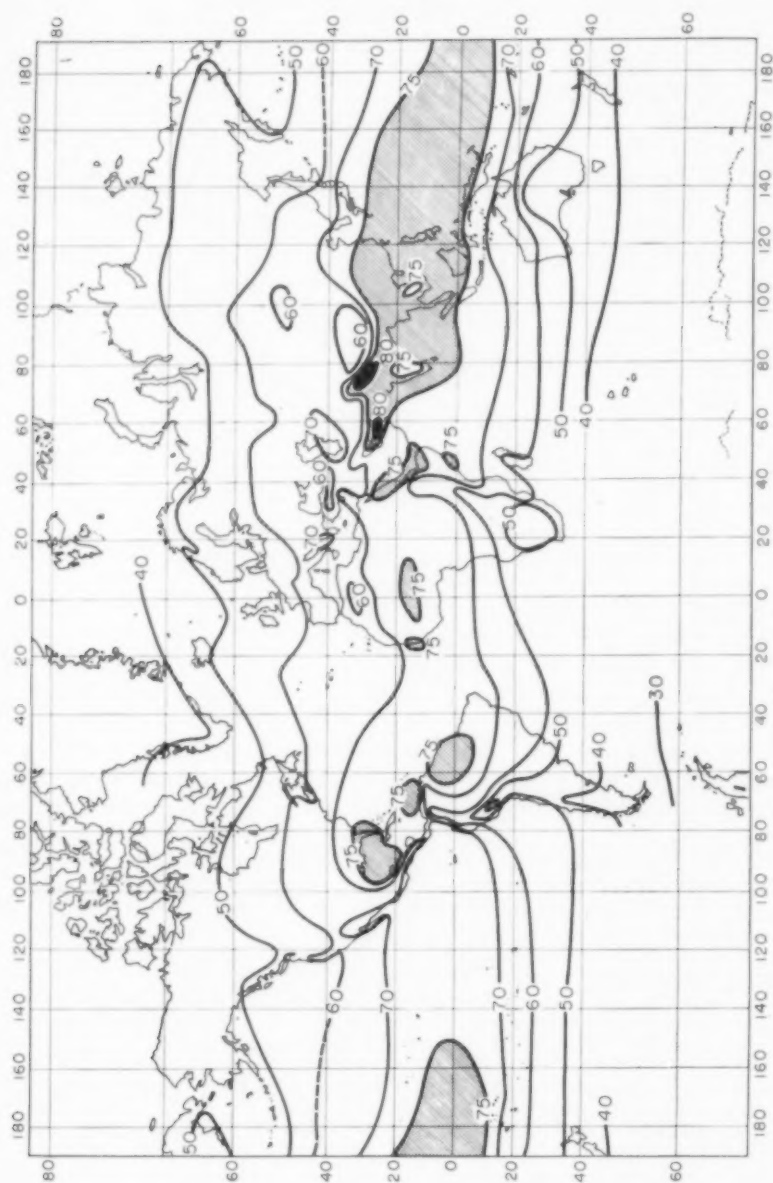
Fig. 16. World wet-bulb isotherms for July (Brooks 1950).

bedrooms are apt to be too warm at early bedtime, and accordingly they should whenever possible be sited on the cool East side of the house before being designed for snugness. An alternative method of climatic correction when the expense is permitted is air-conditioning plus an extra supply of blankets.
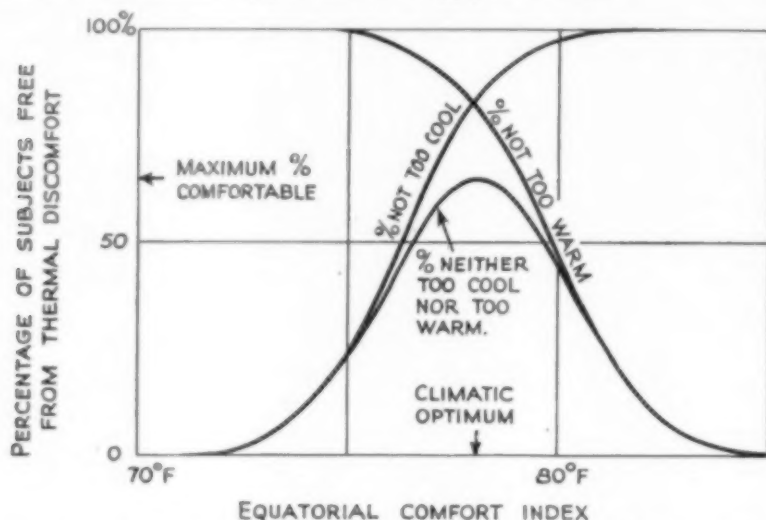
FIG. 17. Comfort graph for fully acclimatized adult males, lightly active, in Singapore.

Coolness by day is to be obtained by horizontal shading, copious ventilation, elevation from the ground, and the avoidance of overcrowding, together with the use of fans. Alternatively the ventilation can be limited and cooling obtained by refrigeration. It seems possible that refrigeration might economically be combined with the use of ceiling fans.

Evening coolness seems to be mainly determined by vertical shading in the late afternoon, by ventilation even more copious than by day, and by the use of fans. Refrigeration is probably hardly necessary in the evenings in ordinary dwellings.

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SIZE, AREA, VOLUME AND WEIGHT OF DUST PARTICLES

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Abstract—A plausible relationship, based on a theorem due to Cauchy, suggests that the mean projected area of a deposit of dust is a quarter of the total surface area. The mean diameter normally measured microscopically is then uniquely related to the surface area of the particles whatever shapes they may be. The rule often fails because particles tend to present their maximum area of cross-section instead of lying in random orientation. The usual surface area shape factor expresses this rather than shape. The logical basis of volume shape factors is imperfect.

Microscope sizing, and to a smaller extent optical screening measurements, tend to give particle sizes which are large in relation to the falling speed of the particles and to their Stokes' diameter. This is due to orientation, to the low density of loosely aggregated particles and to the higher drag of aggregates and extreme shapes. These effects cannot be disentangled, neither is it possible to make a reliable estimate of the drag of a particle of irregular shape from microscope measurements of size.

The implications on sampling dust for preventing pneumoconiosis are that thermal precipitator counts give the impression that the dust is coarser than is really the case while selective sampling, by falling speed, parallels the way in which particles entering the acini of the lungs are separated during breathing.

THE calculation of the surface area or weight of a sample of dust, from measurements of the number of particles and their sizes, is of interest because it is a means of checking bulk methods of finding dust concentration, by optical methods or weighing for example, against standard thermal precipitator counts. It is also important in connexion with size selection when sampling for particles which can reach the acini of the lungs because the mechanisms by which particles of inhaled dust deposit on the surfaces of the lung airways depend on:

 (i) Ratio of particle weight to size for sedimentation and impingement with drag proportional to velocity.
 (ii) Particle size for entanglement (interception).
 (iii) Something between the reciprocal of the size and the reciprocal of the area of cross section, as the particle size falls below one micron, for diffusion.

In addition, the action upon the body of dust which has been inhaled, deposited and retained depends on:

 (i) Weight for soluble poisons and for insoluble, inert dusts which are stored in tissue.
 (ii) Size in connexion with phagocytosis and elimination.
 (iii) Area of surface for slow solution and for chemical and catalytic action.

SURFACE AREA

The relationship between size and surface area does not, as a rule, depend on the shape of a particle. Normal microscopic examination of dust, in which the silhouettes

of particles are compared with circles on a graticule, provides estimates of projected area diameter which is the diameter of a circle having the same area as the particle silhouette.

If the particles are oriented at random their total surface area is equal to four times their total projected area, according to a geometrical theorem due to CAUCHY (1841); this is true for particles of any shape so long as they have no concavities of surface. Clearly, if the surfaces are re-entrant, the area available, for example for gas adsorption, may be many times the apparent macroscopic surface, although this may not be relevant from other points of view, such as optical screening by coal or quartz for which CAUCHY's theorem has been invoked frequently. Failures in this field have been due to incorrect optical theory at least as much as to breakdown of the geometrical law. There is, however, difficulty about random orientation.

ELLISON (1954) found that the apparent area of quartz particles observed after settlement was from 12 per cent to 33 per cent greater than their projected area during settling. WALTON (1947) showed that flat particles of aluminium tended to lie flat and present a greater area after having settled than they did while falling; in this case a tendency to fall edgewise was noted so that the particles were oriented at random neither while falling nor after settlement on the bottom of the vessel. MAY (1960) stated that particles of anthracite coal dust, when examined with the aid of a micromanipulator, were nearly all thin plates, although this was not apparent to ordinary microscopic examination.

ROBINS (1954) actually measured the line of sight thickness of coal dust particles when they were positioned so that it was minimal. He does not publish the measurements in his paper but it can be inferred from the tables given that the thickness of the particle in the line of sight was around a half to a quarter of the projected area diameter, depending on the shape of the silhouette.

It seems, therefore, that sizes determined microscopically are likely to be too large, whether estimated directly from the silhouettes of dust particles or from transparent profiles produced by metal-shadowing at normal incidence (HAMILTON and PHELPS, 1956), because they are derived from settled particles which tend to present their greatest area to observation along a perpendicular direction, although it is uncertain how complete this tendency is and how it depends on the circumstances attending deposition. DONOGHUE (1954) stated that cotton dust does not precipitate in the most stable orientation and WATSON (1954) believed particles to be oriented at random on thermal precipitator slides, but not in the conifuge.

The error might be gauged by measuring, also, profiles produced by shadowing at an oblique angle, although this is not straightforward (WATSON, 1954; GRIGORO-VICI, CROITORU and DÉVÉNYI, 1959). HAMILTON (1954) attempted this and found the median height of coal dust particles to be 37 per cent of the median width when this was 19μ and 58 per cent for $5\cdot9\mu$.

The areas of falling particles, determined by optical estimation or screening, are also liable to error, although to a lesser extent than settled dust. During their fall particles tend to orient themselves unless they are small and possess a high degree of symmetry. The orientation is upset to some extent by Brownian motion and by fluid forces set up when particles are near to one another or to the walls of the container.

Optical measurements of falling particles, or of stirred suspensions, are therefore

likely to give a truer idea of the mean area than those made after settlement or precipitation; the possibility also exists of comparing areas measured in different directions. Areas determined in this way are potentially more accurate than areas calculated from size distribution of settled dust or of shadowed replicas.

The literature of dust microscopy abounds with definitions of various diameters and shape factors. For example, visual counts lead to a distribution of projected area diameter, D, which is evaluated as an average over N particles in a limited size range around D. The total surface area in all ranges is then taken to be

$$\sigma \Sigma N D^2$$

where σ is a surface area shape factor. However, if the orientation of the particles is random and a sufficient number of each shape is present to ensure that every shape is properly averaged, the total surface area is

$$\pi \Sigma N D^2$$

by CAUCHY's theorem; if it is not random σ is an orientation rather than a shape factor, the determination of the latter being impossible without measurements along the line-of-sight. No experimental check has ever been made on the applicability of Cauchy's theorem to an ordinary dust in which no two particles are exactly alike. It is certainly plausible and, if true, means that the mean projected area diameter is uniquely related to the surface area, independent of the shapes of the particles.

VOLUME

As in the case of surface area it is likewise common practice to employ a volume shape factor, v, writing the total volume of the particles as

$$v \Sigma N D^3$$

In a narrow range of N particles of size centred on D the volume is

$$\frac{\pi}{4} \cdot N D^2 t$$

where t is the height of a right circular cylinder, equal in volume to the average volume of the N particles in the range, erected on a circle of diameter D as base. The total volume of all the particles is therefore

$$\frac{\pi}{4} \Sigma N D^2 t$$

If the particles, although of different sizes, are all geometrically similar in shape, and oriented the same way, then

$$\frac{t}{D} = \text{constant}$$

Q

and the total volume is

$$\frac{\pi}{4} \cdot \frac{t}{D} \; \Sigma ND^3$$

so that $v = \pi/4 \cdot t/D$, which is $2/3$ for spheres and smaller for more elongated shapes oriented randomly.

ROBINS (1954) was unable to find a systematic variation of his volume shape factor with size but a flat-topped distribution between the values 0·047 to 0·413, nearly a tenfold range, was demonstrated; the frequencies of five groups over a two-fold range from 0·132 to 0·273 were nearly equal.

The assumption of similarity of shape, which is necessary for t to be taken outside the summation sign, is clearly indefensible and the volume shape factor therefore has no logical basis.

WEIGHT

The rate of fall of a particle and its ability to travel across the streamlines of air flow depend on the weight and the drag. From microscopic sizing a total volume is commonly calculated for a group of particles and multiplied by an assumed density to provide an estimate of the total weight. Appropriate values of diameter and density, however, can only be guessed.

It was shown by the author (1947) that the density of coal dust particles appeared to range from 1 g/cm³ at 1·5 μ diameter to 0·1 g/cm³ at 20 μ. The true density of coal is about 1·4 g/cm³. The difference is partly due to the aggregated nature of the dust, especially the larger particles, which reduces the density by enclosure of air spaces, and partly to the shape of the particles causing increased drag with departure from sphericity.

Even if the weight and shape of a particle were known exactly it would not be possible to say what its drag was and, indeed, the drag would depend on how it moved which, under gravity, might not be by falling vertically but at an angle and might change continually if the particle rotated.

Conversely, should the rate of fall of a particle be measured, as an average over a sufficient height if need be, it is impossible to deduce either its shape or its density.

It is therefore necessary to define quantities which are measurable and those chosen are the projected area diameter, D, mentioned earlier, which unfortunately involves doubt concerning orientation, and the Stokes' diameter, d_s, found by measuring the rate of fall under gravity over a sufficient height to give a good average.

The Stokes' diameter is defined as the diameter of a sphere having the same falling velocity as the particle and a density equal to that of the bulk material from which the particle is made. The qualification about density is invariably omitted from the definition but it is necessary for the practical reason that the density of individual particles is seldom known. Historically this point is of interest because it led to errors in early determinations of the electronic charge and to claims for a sub-electron. With a dust like coal the more complex an aggregate, and thus the lower its density and the greater its drag, the smaller will be the Stokes' diameter calculated from its rate of fall; on the other hand, the complex aggregate will have a greater projected area diameter the looser its structure.

High values of the ratio D/d_s therefore indicate extreme shape, or loose aggregation, or both. For spheres equal in density to the bulk material the ratio is unity.

It is important to remember that the Stokes' diameter should be based on a measured rate of fall. ROBINS (1954), for example, calculated several quantities and distributions involving Stokes' diameter from microscopic measurements of shape. Quite apart from the difficulty about the hydrodynamic drag of oddly-shaped particles, already mentioned, no allowance was made for density of the particles possibly being below the figure for bulk coal.

Correct determinations of Stokes' diameter, using spheres of known density as markers in sedimentation apparatus, have been made by TIMBRELL (1954), using gravitation, and WATSON (1953) and HAMILTON (1954) with a centrifugal device, the conifuge.

Robins' calculated ratio D/d_s for coal dust was 1·56 whereas Watson had found values between 1·31 and 1·35. Robins suggests that the difference may be due to Watson's particles being randomly oriented on the plate of the conifuge whereas he himself had adjusted his particles to present their greatest projected area. This contention is not altogether supported by the experimental results mentioned on page 220. Again, if the particles measured by ROBINS were below 1·4 g/cm^3 in density his calculated Stokes' diameters would have been too large and the correct ratios D/d_s ought to have come out higher still. It therefore seems likely that the high ratio he obtained was due to error in assessing the drag of the particle from its measured shape.

Both TIMBRELL and HAMILTON demonstrate that the projected area diameter of dust particles falling at a given speed, and therefore of the same Stokes' diameter, covers a wide range. The latter found the ratios D/d_s varied from below 1 to 3. The lower limit implies either that some particles had densities exceeding that of bulk coal, perhaps owing to the inclusion of fragments of rock, or that they were elongated particles deposited on the plate in an upright posture so that the projected area was small.

The average effective density (density of a spherical particle with the same projected area diameter and having the same falling speed), however, ranged from 0·33 to 1·1 g/cm^3; some of the deficit below 1·4 must, of course, have been due to the tendency of particles to lie flat and present a large area.

The mean value of D/d_s found by TIMBRELL for coal was 1·35, in agreement with WATSON, no change with particle size being noted between 2·5 and 12·5 μ. The distribution of D/d_s for particles of constant Stokes' diameter again indicated the presence of a few particles for which D was smaller than d_s.

SAMPLING AND PNEUMOCONIOSIS

The foregoing discussion shows that dust particles seen in a sample tend, on the whole, to look larger than their rate of fall would imply for the following reasons.

  (i) They may be flat or elongated in shape and tend to lie flat on the sampling plate so that the observed projected area diameter is exaggerated.
  (ii) They are often lower in density than the bulk material and therefore fall more slowly than would be expected.
  (iii) Owing to their departure from a spherical shape their drag is more than the volume and density would suggest so that they fall slowly.

Referring back to the opening paragraphs of this paper it will be seen that only in respect of entanglement or interception by the surfaces of the lung airways does this tendency to appear large, while falling slowly, operate so as to make deposition in the lungs more effective.

Deposition by interception is a factor of importance only with elongated particles such as asbestos or talc fibres. If these exceed 5 to 10 μ in length (DAVIES, 1957) they get caught in the fine bronchioles and, not being susceptible to transport by phagocytes, produce a disseminated rather than a nodular fibrosis.

For settlement, impingement and Brownian motion the large, elongated or leaf-like particle or aggregate has to be compared in terms of falling speed with a sphere which looks only a fraction of the size. Lung deposition, therefore, will be less than a casual examination of a thermal precipitator sample might suggest.

Once deposited in the lungs of a workman, and recovered years later in the lung residue after post-mortem examination, the particles are likely to appear smaller than they did in the original air sample since all aggregates will have been disintegrated by the extraction process, if not in the lung itself.

These conclusions are extremely relevant to the techniques of sampling for the control of dust disease. On one hand is the question whether the enormously laborious and expensive system of thermal precipitator sampling is so exact as is commonly supposed. On the other is the thought that selective sampling, in which the more rapidly falling particles are eliminated by sedimentation under gravity or in a centrifugal field, operates by a mechanism which parallels closely the mechanisms of the upper respiratory passages for particles over about one micron Stokes' diameter (unit density). Smaller particles whose increasing Brownian motion as the size decreases causes them to diffuse to the bronchial and alveolar epithelium may not be correctly selected but their deposition on the way down to the acinus is probably slight for diameters over half a micron.

Elimination of coarse dust by a selective sampler can be matched, in principle, to the elimination in the respiratory tract, above the respiratory bronchioles, so that the sample collected is identical with the fraction of inhaled dust which is offered to the acinus of the lung. The accuracy of the match depends, of course, upon the precision with which deposition in the upper respiratory tract is known, a subject outside the scope of the present paper which has been discussed elsewhere (DAVIES, 1960).

It is, however, within our scope to point out the poor logical basis for comparing the performance of gravimetric size-selecting sampling apparatus with thermal precipitator samples counted visually. If, out of all the particles visible on the slide only the supposed respirable fraction, say particles below five microns, is counted, the falling speed of some of the larger uncounted particles will be low enough to put them, on this basis, in the respirable range. Microscopic size distributions of a visually selected respirable fraction are therefore normally finer than microscopic distributions made on respirable fractions which have been selected by falling speed.

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THE TOXICITY OF TETRAETHYL LEAD AND RELATED ALKYL METALLIC COMPOUNDS

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THE work to be described has for the most part already appeared in the *British Journal of Industrial Medicine*.

The main purpose of the present paper is to show how biochemical studies can contribute towards the understanding of the mechanism underlying tetraethyl lead poisoning.

A comparison of the action of certain organo-lead compounds has been made under *in vivo* and *in vitro* conditions. In particular the effects of tetra-, tri- and di-ethyl lead and lead acetate have been studied.

Tetraethyl lead is insoluble in water but completely miscible with chloroform, absolute alcohol and similar solvents. Triethyl lead was used as the chloride which is water soluble and ionizes to give a monovalent positive triethyl lead ion.

Diethyl lead dichloride is also water soluble ionizing to give a divalent cation.

Lead acetate represented an inorganic lead ion. Many metals are known to complex with EDTA (ethylene diamine-tetraacetic acid) and with B.A.L. the dithiol compound (2 : 3-dimercaptopropanol). However, tetraethyl lead does not combine with either, nor does triethyl lead. Diethyl lead does combine with B.A.L. but not with EDTA whereas lead acetate combines avidly with both. There is thus this important difference between the inorganic and the organic lead ions.

The onset and development of poisoning in rats after tetraethyl lead and triethyl lead administration appeared to be identical. Within 24–48 hr after injection the rats became very excitable. This was followed by the onset of generalized tremors which became increasingly severe often accompanied by intermittent convulsions leading to death. Rats which did not develop severe tremors recovered within a few days and returned to normal behaviour.

The only difference between the two compounds was that about one and a half times as much tetraethyl lead was required as triethyl lead. The LD 50 being 15·4 and 11·2 mg/kg respectively.

After either diethyl lead or lead acetate there was a loss in body weight but by the end of two weeks the rats were regaining weight and appeared normal.

There was therefore this striking difference between diethyl lead and lead acetate, both of which were relatively non-toxic and triethyl lead and tetraethyl lead which produced identical signs of poisoning.

The system most used for the biochemical studies was that of preparing thin slices of rat cerebral cortex and incubating them in a Krebs–Ringer phosphate medium with glucose supplied as substrate. During the period of incubation the rate of oxygen consumption by the slices was measured and at the end of 1 hr the levels of lactic acid and pyruvic acid were determined.

In a normal brain slice the major portion of glucose used is equivalent to the oxygen consumed. That is to say there is complete combustion to CO_2 and water. The excess of glucose disappearing from the medium can largely be accounted for as lactic acid. The most efficient system as far as energy production is concerned is the one that goes towards complete combustion so that if the metabolism of glucose is incomplete then there will be a lowered production of energy. As is well known, in anaerobic conditions glucose can be metabolised by a variety of cells and tissues but usually stops at the intermediate product lactic acid and the amount of useable energy generated is reduced by one twentieth from that generated during the complete oxidative process.

When triethyl lead is added to slices of brain cortex *in vitro* the oxygen consumption is lowered and the lactic acid content increased, showing that the complete combustion of glucose is inhibited (Table 1). This occurs in the presence of small amounts of triethyl lead, between 7×10^{-7} to 2×10^{-6}M.

TABLE 1. EFFECT OF LEAD COMPOUNDS (ADDED *in vitro*) ON METABOLISM OF SLICES OF RAT BRAIN CORTEX

Compound	Concentration (M)	Percent of control	
		Q O_2	Lactic acid
—	—	100	100
Tetraethyl lead	7×10^{-5}M	100	100
Triethyl lead	2×10^{-6}M	45·5	355
	7×10^{-7}M	86	285
Triethyl lead +EDTA 8×10^{-5}M	7×10^{-7}M	86	315
Diethyl lead	1×10^{-5}M	42	153
	3×10^{-6}M	100	110
Lead acetate	2×10^{-4}M	100	110

Tetraethyl lead, on the other hand, at a concentration a hundred times greater had no effect on glucose metabolism.

Diethyl lead at the same concentration as triethyl lead had virtually no effect. At a higher concentration it did inhibit oxygen consumption but there was only a small increase in lactic acid. This is indicative of a mechanism of inhibition different from that of triethyl lead. This difference has been confirmed in biochemical studies described by the author elsewhere. Suffice it to say that diethyl lead is less active than triethyl lead. Lead acetate at a concentration of 10^{-4} M had virtually no effect.

The result, with EDTA is included in Table 1 because, as stated earlier, chemically it has been demonstrated that EDTA does not combine with triethyl lead. In Table 1 it is shown that biochemically when EDTA was added at a concentration a hundred times greater than that of triethyl lead it did not prevent the inhibition.

A comparison of the results obtained *in vitro* with those of animal experiments *in vivo* showed that there was a good agreement inasmuch as the lead acetate and diethyl lead were relatively non-toxic and had little effect on brain slice metabolism. Triethyl lead was the most toxic *in vivo* and had the most effect biochemically. The anomaly was tetraethyl lead which, although it was nearly as toxic as triethyl lead *in vivo*, it was without effect *in vitro*.

However, when the activity of brain slices prepared from rats previously injected with the different lead compounds was measured an interesting finding emerged. Brain slices prepared from rats given tetraethyl lead 20 mg/kg and killed four hours later showed a lowered oxygen consumption and an increased lactic acid content. The altered metabolic picture was identical to that of slices prepared from rats given triethyl lead chloride 10 mg/kg (Table 2). After diethyl lead dichloride at

TABLE 2. ACTIVITY OF BRAIN SLICES FROM RATS GIVEN LEAD COMPOUNDS
(Killed 4 hours after injection)

Compound	Dose (mg/kg)	Percent of Control	
		Q O$_2$	Lactic acid
Tetraethyl lead ..	20	50	295
	10	80	150
Triethyl lead ..	10	54	330
Diethyl lead ..	40	91	120
Lead acetate ..	100	100	116

40 mg/kg and lead acetate 100 mg/kg there was virtually no change in the metabolism of the brain slices compared with those prepared from control animals.

The anomalous results with tetraethyl lead could be explained by the hypothesis that it is converted in the body to triethyl lead.

A method was developed for estimating specifically triethyl lead in animal tissues. After giving rats tetraethyl lead considerable amounts of triethyl lead could be found in the tissues (Table 3). Furthermore, the pattern of distribution between the tissues was very similar whether the rats had been injected with triethyl lead per se or with tetraethyl lead. In both instances the amount of triethyl lead in the brain was low compared with that found in the other tissues although it did tend to increase between 4 and 24 hr.

TABLE 3. ESTIMATION OF LEAD COMPOUNDS IN TISSUES OF INJECTED ANIMALS

Compound	Dose (mg/kg)	Time after injection (hr)	Triethyl lead found μg/g wet wt.			
			Blood	Liver	Kidney	Brain*
Tetraethyl lead ..	20	4	76	45	23	2·4
	20	24	62	29	25	19·0
Triethyl lead chloride	10	4	65	39	24	4
	10	24	35	30	19	8

* From different animals.

In order to locate the site of the conversion of tetra- to tri-ethyl lead which must have occurred in vivo several systems were examined. The liver is well known for its ability to metabolize a wide variety of foreign substances. Rat liver was therefore tested for its ability to convert the tetra- to tri-ethyl lead and this was done by incubating liver slices in a Krebs–Ringer medium containing tetraethyl lead and at various times samples of the medium were taken and the amount of triethyl lead determined. Results showed that there was a linear rate of production of triethyl

lead over a 90 min period studied (60 μg triethyl lead/g wet wt./hr). When brain and kidney slices were tested in a similar way no triethyl lead was found.

A diagrammatic representation of the sequence of events believed to occur after injecting a rat with tetraethyl lead is given in Fig. 1. It has been previously shown that
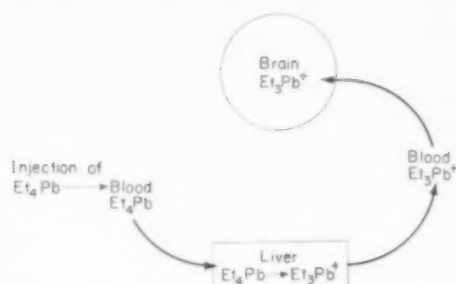
Fig. 1. Schematic representation of the mechanism of tetraethyl lead poisoning *in vivo*.

triethyl lead is stable in the body for at least several days, so that subsequent degradation to diethyl lead or inorganic lead takes place slowly compared with the initial step of tetra- to tri-ethyl lead. Although the amount of triethyl lead found in the brain is low it has been previously calculated that the concentration is sufficient to account for the altered metabolism of glucose observed in brain slices prepared from poisoned rats.

Some preliminary studies have also been carried out with some other alkyl lead compounds namely tetra- and tri-methyl lead and tetra- and tri-propyl lead. None of these compounds were as toxic as the ethyl compounds to rats.

The values given in Table 4 show that there is a larger discrepancy between the toxicity of the tetra-compounds than between the tri-compounds. For instance,

TABLE 4. APPROXIMATE LD.50 VALUES FOR RATS OF SOME TETRA- AND TRI-ETHYL LEAD COMPOUNDS

	mg/kg	
	Tetra-	Tri-
Methyl	105	25–30
Ethyl	15	11·0
Propyl	200	20–30

tetramethyl lead is about seven times less toxic than tetraethyl lead whereas trimethyl lead is only half as toxic as triethyl lead. Results of preliminary experiments indicate that the conversion of tetra- to tri-methyl lead takes place slowly in the rat. Provided sufficiently high doses of the methyl compounds were given it is interesting that both produced signs of poisoning virtually identical to those produced by the ethyl compounds.

After administration of the propyl compounds tremors or convulsions were not seen. On the contrary, the rats became quiet, weak and helpless and died quietly after acute doses within 3–7 days.

Although the biochemical studies described seem to go some way in helping to explain the mechanism of toxicity of certain alkyl lead compounds they do not go far enough. For example, the *in vivo* signs of poisoning seen in rats after giving tripropyl lead are not the same as those seen after giving tri-methyl or tri-ethyl lead and in work on triethyl tin yet another response was seen; but in biochemical studies on brain slices prepared from poisoned animals the altered metabolism of glucose was the same in each case. We have need to look, therefore, for more precise biochemical lesions in nervous tissue, lesions which will be specific for each compound.

REFERENCE

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THE METABOLIC SIGNIFICANCE OF SOME TOXIC SOLVENTS

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Abstract—Some important industrial solvents are described with special reference to the influence of their metabolic products upon bodily enzyme systems and the processes of detoxication by conversion of toxic to non-toxic metabolites.

Among the aromatic hydrocarbons, benzene, toluene and xylene owe the difference in their haemotoxic effect to the fact that only benzene produces toxic phenol compounds, acting on regions of active cell proliferation, while the relative non-toxicity of the alkyl benzenes is related to conjugation of the small amount of metabolic production. Of the halogenated hydrocarbons, carbon tetrachloride is believed to cause liver necrosis by direct disruptive injury of the mitochondria of the liver, to inhibition of oxidative phosphorylation and to release of serum glutamic oxalacetic transaminase (SGOT) from injured liver cells.

Trichloroethanol, one of the chief metabolites of trichloroethylene excreted in the urine, is now widely regarded as a better criterion of exposure than trichloracetic acid.

The ocular injury caused by methyl alcohol is probably due to a primary inhibition of retinal glycolysis by its metabolites formaldehyde and formic acid, and the renal injury characteristic of the glycols to the metabolic formation of oxalic acid.

The relation between the long-term arteriosclerotic effect of carbon disulphide and the chelating effect of dithiocarbamates formed during its metabolism on the metal ion complexes necessary for normal metabolism is discussed.

During the last twenty years there has been an outpouring of books and articles describing in full detail the toxic effects, both actual and potential, of practically all the solvents used in industry. It is only comparatively recently that these toxic effects have been related to the passage of foreign substances through the body, their conversion within the body to compounds which are or more or less toxic than the original substances, the processes of elimination and what has been called "detoxication", and the interrelationship of toxic effects and bodily enzymes. This is an extremely important and interesting aspect of the subject, verging closely on the mysteries of biochemistry, with deep and learned investigations difficult to understand perfectly by anybody but a dedicated biochemist and apparently not always even by him.

Nevertheless the results of these researches have certainly elucidated many problems and opened up new ones. It is such a vast subject that in this short review I can only hope to touch the fringes of it. I intend therefore to deal only with some of the more important and better known toxic organic compounds used in industry, with a few of the newer ones whose toxicity has become apparent and whose metabolic transformations have been investigated.

We all know, sometimes from bitter experience, what are the external manifestations, that is to say the symptoms and signs, of poisoning by toxic solvents, but we

do not always understand why these effects are produced or why some compounds, even those belonging to the same chemical groups, produce such different effects. The reactions involved in the process of metabolism of foreign organic compounds are in many instances similar to the products of the normal metabolism of foodstuffs or of their bacterial decomposition in the intestinal tract. It was recently remarked by Dr. Sexton of I.C.I. that "even the simplest of compounds, water, is biologically active, since it participates not only as a solvent but also as one of the most important reactants in the living cell. Living organisms are really dynamic physico-chemical systems, and the structure of every molecule must be viewed in relation to its environment and to its metabolic precursors and successors."

A special mechanism for dealing with exogenous toxins appears to exist in the microsomes of the liver, which contain enzymes able to deal with a number of these foreign substances but not with the natural products. The reactions involved in this process of metabolism of foreign substances have been described as occurring in two phases—the first, the toxic phase, includes oxidation, reduction or hydrolysis or a combination of these; the second, the non-toxic, the synthesis by means of conjugation into substances such as ethereal sulphates, glucuronides or hippuric acid, which can be harmlessly excreted. If the process of conjugation, primarily a function of the liver, is slower than that of the oxidation phase, some of the metabolites are left free to exert their harmful action on the living cell and the enzymes contained in it.

The biological enzyme is a catalyst peculiar to living matter. As in chemistry, a catalyst in biology accelerates a reaction and is not itself consumed in the process, but it must have a substrate to work upon, and it is usually according to the particular substrate that the enzyme is named by adding the suffix "-ase". Thus, the enzyme which attacks urea is urease, that which attacks phosphate, phosphatase. Many of these enzymes have now been isolated as pure crystalline substances and their actions studied *in vitro*. Some of them require the presence of metal ions such as manganese, zinc or copper; others require what are known as co-enzymes, in order to carry out their activity. Some are of general importance in metabolism, others are highly specific, but a very large number are involved in the mechanism of our "biological machine", and any interference with their complex interrelated reactions will cause disturbance of the whole organism. This disturbance may sometimes be neutralized by the compensating reactions of detoxication. If not, they will produce severe or even lethal toxic effects. An outstanding example of the effect of inhibition of an enzyme is that of organic phosphorus insecticides on the nervous system. The enzyme which catalyses the acetylation of choline to acetylcholine (the substance deeply concerned with nervous mechanisms) is cholinesterase. Cholinesterase thus plays a key role in nerve transmission and the measure of its decrease in the blood is a measure of the toxicity of some of the organic phosphorus compounds.

The concept of the enzymatic system concerned in the process of cell respiration has undergone great development since Keilin in 1925 described the role of the cytochrome system. He then stated that a chain of enzymes was required to transfer hydrogen atoms in successive steps from substrate to molecular oxygen. The series of rapid reactions composing the cycle by which carbon dioxide and water, the main end-products of respiration, can be produced from organic substances, was first described by Krebs in 1935, and was called the Krebs or tricarboxylic cycle.

The conversion of organic to inorganic phosphate represents the transformation of chemical energy in living matter, and in 1941 Kalckar said that "the classification of the coupling between the triosephosphate oxidation and the uptake of organic phosphate represents one of the greatest advances in modern biology". Since then much research has been done on the mechanism of oxidative phosphorylation, which is the essential source of energy in cellular processes. Toxic substances which can uncouple, or inhibit, the phosphorylation process cause injury to the mito-chondria and to the vital processes of cell metabolism.

Every normal tissue is characterized by a unique balance between the various enzymes concerned in metabolism; they are in fact a fundamental ingredient of life processes, and any injury of them by a toxic substance is likely to have far-reaching effects on the body as a whole. I have already mentioned that the process of de-toxication by conversion of toxic into non-toxic metabolites is carried out chiefly in the liver. Liver cells are rich in the mitochondria which contain the enzymes necessary to catalyse this detoxication.

Mitochondria are particles suspended in the cytoplasm of all animal cells. Some-times, as seen by the electron microscope, they appear as long filamentous threads, sometimes as rods and spheres, and they have been isolated by differential centri-fugalization. Some of the enzymes and co-enzymes are highly organized within the mitochondria, and since many of the vital systems of oxidation, reduction and the primary sources of energy are represented in these enzymes it is not difficult to realize that anything which disrupts these minute bodies can inflict vital injury upon the whole organism. It is by such disruption and injury that the metabolic products of many toxic agents exert their harmful action. It is also by the capacity of these enzymes to initiate the reactions which convert the harmful into less harmful metabolites that the mechanisms of detoxication can be carried out.

This is a very brief attempt to achieve some explanation of the toxic potentiality of various organic substances and especially of the variety of manifestations of toxic action of members of the same chemical groups. Taking the group of *aromatic hydrocarbons*, the outstanding example of this latter difference is shown in those well-known solvents, benzene, toluene and xylene. It has long been accepted, and anyone who has had practical experience of examining the blood picture of workers exposed to these solvents can confirm it, that the only member of this group with a true dyshaemopoietic effect is benzene. When there is any evidence of a benzene-like depressant effect on the bone marrow following chronic exposure to toluene or xylene it is because these solvents contain a certain amount of benzene, as most commercial varieties do.

The metabolites of benzene are phenol, quinol, pyrocatechol and hydroxyquinol with the minor metabolites muconic and mercapturic acid. These phenol metabolites, products of the phase of oxidation (the toxic phase), now undergo the second, non-toxic, phase of conjugation with sulphuric or glucuronic acid, and appear in the urine as ethereal sulphates. In this form they are detoxicated; it appears that the phenol metabolites can only exert their toxic action so long as they are free. But if the process of conjugation is slower than that of oxidation, or if it is impaired by other factors, the free metabolites, especially quinol and catechol, which are mitotic poisons, can exert their toxic action, and this they do most significantly in regions of active cell proliferation such as the bone marrow.

Some interesting observations on the correlation of chronic benzene poisoning with alterations in the enzyme systems have recently been made in Italy (GABOR, 1959). In animals subjected to long-continued inhalation of low concentrations of benzene vapour, changes in the activity of enzymes concerned in oxidation-reduction processes appeared earlier than the blood changes. The most important change was an initial antagonism between catalase and peroxidase, the former decreasing as the latter increased, but both decreasing with increasing concentration of the inhaled benzene. This initial antagonism was regarded as an adaptation reaction of the organism, an indication of a stage of functional disturbance; its disappearance as an indication that the possibility of detoxication had been overcome and that morphological changes had been superimposed on the functional.

The failure of toluene and xylene to carry out this attack on the bone marrow is due to the fact that their metabolites are not the toxic phenols (PORTEOUS and WILLIAMS, 1949). Toluene is converted to benzoic acid; this, in the presence of adenosine triphosphate and co-enzyme A, is conjugated with glycerine to hippuric acid which is excreted in the urine. In fact, the amount of hippuric acid in the urine has been suggested as a measure of exposure to toluene vapour (CHANTRENNE, 1951), just as the change in the proportion of organic to inorganic sulphates in the urine has been considered evidence of absorption of benzene by persons exposed to it, though not as a measure of its toxic action.

The xylenes are oxidized mainly to toluic acids, which are almost entirely excreted as glycine conjugates.

The *alkyl benzenes*, of which the most commonly used as solvents are ethyl, propyl and butyl benzene, triethyl and trimethyl benzene (mesitylene), are also devoid of the characteristic haemopoietic effect of benzene.

They are irritant to mucous membranes, causing increased permeability of the capillaries, and therefore oedema and haemorrhage in the surrounding tissues, and have also a narcotic action due to their special affinity for nerve tissue. One of these, p-tertiary butyl toluene, is reported to be a highly neuro-toxic compound; this action is believed to be due to secondary haemorrhage in nerve tissue resulting from vascular injury (HINE, UNGAR and ANDERSON, 1954). None of them, however, has a myelotoxic effect. It appears that any change in the benzene ring, such as hydrogenation, alkylation or sulphonation results in loss of the specific myelotoxicity of the benzene molecule (SCOTT, CARTWRIGHT and WINTROBE, 1958).

GERARDE (1959) has in fact urged that the name *alkyl benzene*, with its implied similarity to benzene, should be changed to *phenyl alkanes*, which toxicologically they are.

When inhaled, these compounds are for the greater part eliminated by the lungs unchanged. The small amount metabolized is excreted in the urine in the form of conjugates with glycine or glucuronic acid. Another difference between the alkyl benzenes and benzene lies in their acute toxicity. Isopropyl benzene, or cumene, for example is more acutely narcotic than benzene. This is due to the rate of metabolism. Although benzene is rapidly removed from the blood stream, its metabolic route of elimination is slow compared with the purely physical process of evaporation from the blood into the alveolar air.

Trimethyl benzene has two isomers, 1-2-4-, or pseudocumene, and 1-3-5-, or mesitylene. The latter is the more widely used in industry. In Germany a thinner

known as Fleet X contains more than 80 per cent of trimethyl benzene (BATTIG, GRANDJEAN *et al.*, 1958). With concentrations of 10 to 60 p.p.m., workers have shown some central nervous disturbance in the form of lassitude, giddiness, headache and drowsiness. There was also some anaemia, with delayed coagulation time and a tendency to spontaneous haemorrhage, but no thrombocytopenia and no benzene-like changes in the blood picture. The blood disturbances were in fact attributed to a vitamin C deficient diet. Animals exposed to chronic inhalation showed no significant variation of the blood picture, but did show some central nervous disturbance in the form of ataxia and narcosis which was reversible on cessation of exposure.

The chief metabolic product of trimethyl benzene is dimethyl benzoic acid, which is reported to be excreted partly as the glycine conjugate, but according to Battig and Grandjean, who made these observations, prolonged exposure was also followed by an increased excretion of phenols, both free and bound, in the urine. On account of its resemblance to benzene in this respect, although it has shown itself to be a neurotoxic rather than a haemopoietic poison, these authorities suggest that it should not be regarded as an entirely innocuous substance.

THE CHLOROBENZENES

Some of the chlorinated benzenes such as p-dichlorobenzene, tri-, tetra- and hexachlorobenzene, are solids, but monochlorobenzene and o-dichlorobenzene are liquids and are used as solvents, the former for ethyl cellulose, oils and fats, the latter also for resins and lacquers and in paint and varnish removers.

The toxic action of all the chlorobenzenes is that of a central nervous poison, and the degree of acute toxicity increases with the substitution of the chlorine atom in the benzene ring up to 2, and thereafter decreases. Thus, the M.A.C. for monochlorobenzene is 75 p.p.m. and for o-dichlorobenzene 50 p.p.m.

Monochlorobenzene has not actually been reported as causing any cases of industrial poisoning; its central nervous toxicity has been deduced from fatal cases following ingestion, when it has caused cyanosis, loss of reflexes, twitching of the facial muscles and unconsciousness (REICH, 1934). Dichlorobenzene also has caused no industrial symptoms other than severe dermatitis (DOWNING, 1939), but in animals it has produced renal damage and liver necrosis (CAMERON and THOMAS, 1937).

The more chlorine the halogenated benzenes contain the less readily they are metabolized. Thus tri- and pentachlorobenzene are only slightly altered in the body, and hexachlorobenzene, used as a seed fungacide, appears to be metabolically inert (PARKE and WILLIAMS, 1960). None of these compounds form conjugated glucuronic ethereal sulphates or mercapturic acids. Monochlorobenzene, of which about 30 per cent is eliminated by the breath is, however, also oxidized to phenols, which are excreted chiefly in conjugation with glucuronic and sulphuric acids, and to some extent as mercapturic acid. It is in the quantitative excretion of mercapturic acid that there lies the main difference between the metabolism of monochlorobenzene and benzene itself. While monochlorobenzene produces 20 per cent of mercapturic acid, benzene produces not more than 1 per cent of the administered dose (AZOUZ, PARKE and WILLIAMS, 1952).

The metabolism of o-dichlorobenzene is qualitatively similar to that of monochlorobenzene in that it gives rise to catechols and phenols which are excreted in

conjugation with glucuronic and sulphuric acids, but it differs quantitatively in small amounts of catechol and mercapturic acid, and in the slower excretion of these metabolites (PARKE and WILLIAMS, 1955). Benzyl chloride, or -chlorotoluene, used extensively in the manufacture of pigments, resins and perfumes and in intermediates in the preparation of acid dyes, has as its chief toxic effect a severe irritation of mucous membranes, especially of the eyes. It has in fact been classified as a powerful lachrymator, and this property may account for the lack of reports of systemic effects. It is so unpleasant that 1 p.p.m. has been suggested as the M.A.C. It thus provides its own warning. Its metabolic behaviour differs in one respect from the other halogenated benzenes. While some of these eventually produce mercapturic acid through intermediate precursors known as premercapturic acids, benzyl chloride is converted directly *in vivo* to this substance, and at least 10 per cent of the dose can be eliminated in the urine as benzyl mercapturic acid (KNIGHT and YOUNG, 1958).

THE HALOGENATED HYDROCARBONS

Among the halogenated hydrocarbons many are so volatile that although appreciably toxic the major part is excreted by the lungs, with little left in the tissues to produce potentially toxic metabolites. How far the actual toxicity of some of them is due to enzymatic disturbance or to injury of the mitochondria is not completely clear. The most toxic of all, tetrachloroethane, is metabolized and eliminated rather slowly, and oxalic acid has been suggested as one of it most injurious metabolites.

Carbon tetrachloride is very widely used, as a fire extinguisher, a solvent for rubber, a grease remover and a dry cleaning agent. Most of its toxic effects have been reported from the point of view of acute toxicity, when severe damage to liver and kidneys has been found. The liver lesion following a large dose is a centrilobular necrosis. If it is not too massive repair may begin in three or four days and may be complete in two or three weeks. With chronic exposure the symptoms are mainly gastro-intestinal with nausea and vomiting, also headache, dizziness and excessive fatigue. Jaundice is rarely present. There is some disagreement as to the actual mechanism by which CCl4 produces its hepatotoxic effect. Examination of the livers of rats to which it has been administered by stomach tube has shown hydropic globules in the cells. These contained succinoxidase and ribonucleic acid, suggesting that they were derived from mitochondria, and most authorities consider that the primary biochemical lesion is the result of a direct structural attack on the mitochondria themselves. This disrupts their function, depriving them of their ability to retain the small amount of co-enzyme which they possess, thus disorganizing their whole enzyme system.

The measurement of oxidative phosphorylation is a sensitive indicator of mitochondrial damage, and it has been found that this is inhibited *in vivo* in the liver of rats treated with CCl4. The morphological changes in the liver have occurred some time before the oxidative changes could be detected (CALVERT and BRODY, 1958). It is also interesting to note that in a recent investigation in sheep by ALEXANDER and MACDONALD (1960) oxidative phosphorylation survived a long time and no significant change took place in the level of plasma alkaline phosphatase. This may lend support to the findings of STEWART and MILLS (1944) that early changes in the liver are reversible, and indeed more recent researches (OBERLING, 1959) have shown

that there is intense mitochondrial regeneration after CCl_4 intoxication. On the other hand, a somewhat ominous suggestion has emerged from the observations of Andervont in 1958 in his demonstration that CCl_4 has a carcinogenic action on the liver of the mouse.

Another method of measuring slight changes in liver cells not demonstrable by clinical examination or by the usual tests for liver function is that of estimation of the level in the blood stream of an enzyme known as serum glutamic oxalacetic transaminase, or more shortly SGOT. Transaminases are widely present in animal tissues and in blood. They catalyse an aminoacid reaction, and when cells rich in these enzymes are injured increased quantities of transaminase are released into the blood. This is especially the case with injury from hepatoxic agents such as CCl_4, and an increase of SGOT is regarded as a highly sensitive indication of CCl_4 injury to liver cells. This has been confirmed in animal and human beings (BLOCK and CORNISH, 1958; WROBLENSKI and LA DUE, 1955, 1956). In men acutely poisoned by CCl_4 the rise of activity of transaminase has been particularly striking. In two cases the rise in the level of the enzyme two days before admission to hospital was 27,840 and 12,340 units respectively, as compared with the normal range of 6 to 40 units. In both cases there was a return to normal values within a week.

Some even more recent work on the influence of CCl_4 on the bound enzymes of the liver indicates that the hepatotoxic action may be related to the release of intra-cellular enzymes segregated in a group of cytoplasmic particles distinct from mito-chondria and known as lysosomes. When the membrane of these particles, probably of a lipoprotein nature, is injured, they release a collection of soluble hydrolytic enzymes which may play an important part in the necrosis of liver cells. This extremely careful and complex investigation by BEAUFAY and co-workers (1959) also revealed a time factor in morphological and biochemical manifestations—the enzyme alterations were present as much as several hours before detectable micro-scopical liver lesions.

TRICHLOROETHYLENE

The acute toxic effect of trichloroethylene, if one can call surgical anaesthesia a toxic effect, is too well known to need repetition. It is a powerful narcotic, and when inhaled in high concentrations rapidly produces complete unconsciousness.

With chronic exposure there is also evidence of its predominant effect on the nervous system. It has been reported to cause vague nervous symptoms, headache, drowsiness, giddiness, fatigue, insomnia and intolerance to alcohol.

Whether it has a chronic toxic effect on the internal organs, especially the liver, as in the case of CCl_4, has been much discussed. On the whole the concensus of opinion is that it has no such hepatotoxic action, but there has recently been one report from Italy (CAPELLINI and GRISIER, 1958) suggesting that it may have caused slight functional disturbance of the liver. Among twelve women chronically exposed, some showed, in addition to slight dyspeptic symptoms, slight enlargement of the liver and an increased level of bilirubin in the blood.

Estimation of the serum transaminase, already described as an indication of liver cell injury, have however shown no such increase as that observed with CCl_4, and GRANDJEAN (1959) is of the opinion that it occurs only in persons with a predisposi-tion to liver disorder.

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Trichloroethylene has quite a remarkable metabolic performance. It forms the two main metabolites, trichloracetic acid and trichloroethanol, together with a number of others which include urocholalic acid, monochloracetic acid, chloroform and chloral hydrate (MARSHALL and OWENS, 1954). Both trichloroethanol and tri-chloracetic acid are excreted for a long period following exposure, probably owing to the slow release of trichloroethylene retained in the tissues where it is suggested that it is bound to protein (BARTONICEK and SOUCEK, 1959). Chloral hydrate is the first to appear in the blood stream. The free trichloroethanol shows an initial decrease, due to partial conjugation with glucuronic acid, but both fractions are recoverable from the blood for at least 15 days. Trichloracetic acid is the last metabolite to appear in the blood, its maximum concentration being present about 50 hr after inhalation, but it also remains for 15 days.

Following the statement in 1939 by BARRETT and JOHNSTON that the amount of trichloracetic acid in the urine can be correlated with the amount of trichloroethylene inhaled, it was at one time believed that the best estimation of trichloroethylene exposure might be that of urinary TCA. More recent investigations of the relation between the primary metabolites of trichloroethylene, in workers in a dry cleaning establishment in Italy (RUBINO, SCANSETTI et al., 1959) have suggested that though the urinary TCA is a good criterion of its own presence in the blood, it is not strictly correlated with the amount of trichloroethylene itself either in the blood or in the environment, and that trichloroethanol is a preferable criterion. Trichloroethanol, both free and conjugated, is present in the urine in much larger amount than TCA.

In both massive and chronic intoxication 68 per cent of the metabolic excretion is represented by TCE as against 32 per cent by TCA, and there is apparently much closer correlation of the TCE in blood and urine with the level of trichloroethylene in the atmosphere and in the blood. Also there is such a wide individual variation in the excretion of TCA that it has come to be regarded as a not wholly reliable guide to the amount inhaled, though a statistical analysis by Grandjean and co-workers in 1955 indicated that subjective, vegetative and neurological disturbances were more common in workers excreting an average amount of 67 to 180 mg per litre than in those with an average of 20 mg per litre.

DICHLOROETHANE

Dichloroethane has two isomers, 1-1- or ethylidinechloride, and 1-2- or sym-ethylene dichloride. The latter is the more important industrially, being a low-priced, efficient solvent for resins, rubber, cellulose acetate and lacquers. It is also used in the production of ethylene glycol, as a degreaser for metal and wool, as an extraction solvent for soya bean and caffeine and as an insecticide and fungicide. From the point of view of acute poisoning it is a powerful narcotic and was at one time recommended as an anaesthetic. Acute toxicity from its industrial use has not been frequently recorded considering its wide application, but four cases were reported in 1957 (MENSCHICK) in men painting the inside of a container which had held it. One man became unconscious in ten minutes after an attack of vomiting, and on recovering had muscle spasms and severe gastro-intestinal disturbance.

Two others had a latent period of about an hour before developing gastric symptoms, giddiness and weak heart action, and both showed signs of disturbance of liver function.

Dichloroethane is generally regarded as having a much less toxic action on the liver than CCl₄, tetrachloroethene or chloroform, but that it can affect the liver and kidneys is evident from fatal cases following accidental ingestion. Four such cases were described in 1957 (WEISS) and MOROZOV (1958); in all there were toxic hepatitis and nephrosis. In animals the liver damage caused by acute exposure is less than with CCl₄, but it causes a temporary corneal opacity due to an infiltration of the cornea by lymphocytes and connective tissue cells. It is interesting to note that this effect was observed in human beings as early as 1887 when its use as an anaesthetic was first suggested (DUBOIS and ROUX). It is the only saturated chlorine compound of the ethane series which has this action (HUEPER and SMITH, 1935).

Its metabolism has not been thoroughly elucidated. In animals it is mainly exhaled unchanged and no metabolite has been definitely isolated, but it has been suggested that like other halogenated hydrocarbons it is dehalogenated *in vivo* by a hydrolytic enzyme occurring in the liver, kidney and spleen. Other views are that one of its metabolites may be oxalic acid (HUEPER and SMITH, 1935) or that the toxic effect may be due to the non-metabolized molecule itself rather than any metabolite (HEPPEL, NEAL *et al.*, 1945).

Trichloroethane, or methyl chloroform, also has two isomers, 1–1–1– and 1–1–2–. It has solvent properties similar to those of CCl₄ and is used for many similar purposes. Both isomers are narcotic. The 1–1–1– isomer was studied by Adams and co-workers in 1950; they found the principal toxic effect of single exposures in animals to be a central nervous depression typical of an anaesthetic agent. In such anaesthetic dosage there was some evidence of liver injury, relatively slight, but resembling that of CCl4 in that the central portion of the lobule was more severely affected than the peripheral. With repeated exposure also the liver damage was slight, and it appeared that animals could tolerate much greater exposure to trichloroethane without injury than to CCl4. Little is known of the metabolism of either isomer, but it does not yield trichloracetic acid in the urine as does trichloroethylene.

THE ALCOHOLS

The primary alcohols, methanol, ethanol, propyl, butyl and amyl alcohol, are the most widely used in industry. Except for the specific injury peculiar to methanol, they are not highly toxic, though inhalation of high concentration of their vapours can cause some of the manifestations typical of excessive ingestion. Their hypnotic activity, when given by mouth, increases with their molecular weight (VON OETTINGEN, 1943). It can also be correlated to some extent with their conjugation with glucuronic acid. There is little conjugation with the primary alcohols but an increasing amount with the secondary and tertiary, with a corresponding increase in narcotic potency of the latter. Correlation of their toxic action with their metabolic fate is best exemplified by the difference between methyl and ethyl alcohol.

Ethyl alcohol is metabolized chiefly in the liver, other organs play a secondary and subsidiary part. Its oxidation takes place in steps, an intermediate metabolite being acetaldehyde, which is itself readily oxidized to acetic acid; this in its turn

in normal conditions is rapidly further oxidized in the tissues to CO_2 and water (BLOCH, 1947; BARTLETT and BARNET, 1949). The enzyme concerned in the first step is alcohol dehydrogenase, which catalyses the transference of hydrogen from alcohol to disphosphorydine nucleotide, with the formation of acetaldehyde and reduced DPN, as follows:

$$\text{Alcohol} + \text{DPN} \rightleftharpoons \text{Acetaldehyde} + \text{DPNH} + \text{H}^+$$

The reaction is not specific for ethyl alcohol but occurs also with propyl, butyl and amyl alcohol; it does not occur with methyl alcohol. Methanol is oxydized in its first step to formaldehyde and then to formic acid which is partly excreted in the urine, the remainder to CO_2 which is expired. There is also some formation of methyl glucuronide, which has also been found in the urine (KEESER and VINCKE, 1940). These transformations are effected not by alcohol dehydrogenase but more probably by a catalase mechanism which has been suggested as a secondary mechanism in the conversion of ethyl alcohol to acetaldehyde. In any case the metabolism of methyl alcohol is four or five times slower than that of ethanol.

The characteristic toxic action of methyl alcohol on vision is due to the high toxicity of these metabolites and to the slowness of its elimination. Formaldehyde has been detected in the aqueous and vitreous humour of the eyes of rabbits poisoned with methanol and formaldehyde is extremely active in inhibiting oxygen uptake and CO_2 production. Blindness due to methanol has usually been due to excessive ingestion, but it has been reported as the result of inhalation. In fact by 1912 over a hundred cases of death and blindness following inhalation had been described (ROBINSON, 1918). It appears that the primary visual lesion is in the retina —an inhibition of retinal glycolysis probably due to a disturbance of phosphorylation (POTTS and JOHNSON, 1952). This is followed by lesions of the optic nerve, ultimately developing into optic atrophy.

Actually, few investigations of the effects of chronic exposure to the vapour of methanol in industry have been made. One of these was carried out in this country in 1952 (LEAF and ZATMAN), in a factory where the air concentrations in a methanol synthesis and distillation were analysed. In the synthesis plant these were very low, less than 5 p.p.m.; in the distillation plant in the late afternoon they reached 64 p.p.m. and in the stripping plant a maximum of 116 p.p.m. No more than traces of methanol were found in the urine of the workers. As a result of calculations of the absorption and elimination of methanol it was suggested that exposure to 3000 p.p.m. would cause sufficient accumulation to represent a toxic hazard, and that the safe limit should be fixed at 300 p.p.m. The present recommended M.A.C. is 200 p.p.m.

Among the other primary alcohols, n-propyl, and n-butyl are the most widely used as solvents for gums, resins, oils and cellulose ethers and esters; n-butyl also in the lacquer and dye industries.

From the narcotic point of view, n-propyl alcohol is twice as potent as ethanol, and n-butyl even more so, but the only toxic effect reported is the development of an unusual form of keratitis from the use of n-butyl alcohol (COGAN and GRANT, 1945). The symptoms observed in workers applying a synthetic resin dissolved in butanol to Army raincoats were irritation of the eyes and in some cases blurring

of vision. The lesions seen under transillumination consisted of clear translucent vacuoles in the superficial layers of the cornea. These were especially numerous in the central portion of the cornea; in the most severe cases they were about 500 to 1000 in number. The condition improved, and in some cases completely resolved, within ten days of absence from work but recurred a few days after further exposure.

The metabolism of n-propanol is characterized by its oxidation at a constant rate to propionic acid, which is then presumably further oxidized to CO_2 and water. Very little is conjugated, only large doxes producing about 1 per cent of glucuronides.

With n-butanol there is also rapid oxidation, but about 2 per cent of the dose is conjugated.

Of the secondary alcohols, the most important industrially is *iso-propyl alcohol*, which has a fairly wide use as a solvent. It is nearly twice as narcotic to animals as ethyl alcohol, but causes no such visual disturbance as methyl alcohol, and only a moderate fatty infiltration of the liver and kidneys. No ill effects have been reported from its industrial use. Its greater narcotic effect than that of ethyl alcohol is attributed partly to its slower rate of metabolism. Part of it is conjugated with glucuronic acid, but it is oxidized in the body chiefly to acetone, most probably catalysed by alcohol dehydrogenase. WILLIAMS (1959) remarks that since acetone is slowly converted to acetate, formate and CO_2 it seems reasonable to conclude that isopropanol may also form these compounds. *Isobutyl alcohol* is not of great industrial importance. It is used to a small extent in the lacquer industry. Like the other alcohols it is narcotic to animals, to about the same extent as n-butyl alcohol, but it has not been reported as causing any toxic effects in man. It is metabolized by oxidation to methyl ethyl ketone and partly conjugated to secondary butyl gluconuride.

THE CHLORINATED ALCOHOLS

With the substitution of a chlorine group the narcotic potency increases, and the members of this group show a higher degree of conjugation when two or more chlorine atoms are present. Thus, whereas ethanol is largely oxidized to acetic acid, trichloroethanol, a much more active narcotic, is converted in the body partly to the trichloroethyl glucuronide (urocholalic acid), partly to trichloracetic acid.

The most toxic of the chlorinated alcohols is monochloroethanol, or *ethylene chlorohydrin*. This is a colourless mobile liquid, used chiefly in the chemical industry in the manufacture of ethylene glycol, but also as a solvent. In 1927 KOELSCH described two fatal cases following its use, in one case, for cleaning a machine, in the other as a solvent for pigments. In both cases exposure had been considerable. The symptoms preceding death were nausea, vomiting, headache and giddiness. It was nearly twenty years later that a further series of cases were recorded, two fatal and nine non-fatal, during the manufacture of this compound (GOLDBLATT and CHIESMAN, 1944). In one of the fatal cases death occurred 14 hrs after exposure and again in both cases the symptoms were those of gastro-intestinal disturbance and central nervous affection, including mental confusion. In neither case did autopsy reveal clearly the cause of death.

Animal experiments showed that lethal concentrations (1120 p.p.m.) caused renal haemorrhage and tubal degeneration and fatty degeneration and necrosis of

the liver. With high but not lethal concentrations there was inhibition of the heart's action and respiration, and of smooth muscle and nerve transmission.

These toxic effects are ascribed to its metabolic characteristics. It does not give rise to a glucuronide, at any rate in the rabbit (WILLIAMS, 1959), but is probably oxidized to monochloracetic acid which is 20 to 40 times more toxic than acetic acid, and to its di- and trichloro-derivatives, metabolites of di- and trichloroethanol.

THE GLYCOLS

The glycols, ethylene, propylene, butylene and diethylene, and their ethers and esters, are used to some extent as solvents chiefly for cellulose and nitrocellulose, and as vehicles for pharmaceutical preparations and skin lotions. Ethylene glycol itself is best known as an anti-freeze mixture for automobiles. It is not sufficiently volatile to be an industrial hazard in normal circumstances, though there has been one report from Italy (TROISI, 1950) of chronic poisoning from inhalation of the vapour from a mixture containing 50 per cent of it when heated to 105 °C. The chief symptoms were recurrent attacks of unconsciousness, and some of the affected women showed nystagmus. These toxic effects were attributed to its action on the central nervous system.

When taken internally, ethylene glycol is extremely toxic. In fatal cases death has been due to renal failure, with crystals of oxalic acid deposited in the renal tubules. In fact, in poisoning by any of the glycols or their derivatives the outstanding toxic effect is exerted on the kidneys.

Propylene Glycol is about half as acutely toxic as ethylene glycol, and very much less by repeated oral administration. Injury to the kidneys, in the form of casts and haemorrhages, has been produced by fatal intravenous injection, but continued feeding in concentrations of 2·45 to 4·9 per cent of the food for several years did not cause the deposition of oxalic acid stones as with ethylene glycol. Neither from propylene nor butylene glycol have there been any reports of injury to human beings.

Diethylene Glycol is also said to be about half as toxic as ethylene glycol, judging from their minimal fatal doses for animals by intravenous injection. When mixed with food it was fatal to some animals in concentrations of 5 to 10 per cent within a few weeks. Some of these animals showed stones of calcium oxalate and phosphate in the bladder, and damage to the kidneys consisting chiefly of extensive injury to the tubules, causing obstruction and uraemia.

The toxicity of diethylene glycol for human beings was strikingly illustrated by a series of deaths in U.S.A. in 1937 from the use of an "elixir of sulphanilamide" of which the vehicle was diethylene glycol (RUPRECHT and NELSON, 1937). The symptoms included nausea, dizziness, pain in the abdomen and kidney region, and in the course of a few days oliguria and anuria with a final development of uræmic coma. The most characteristic injury was found in the kidneys—what was called a "chemical nephrosis".

Dipropylene Glycol is apparently less toxic but in large doses has produced similar though less severe kidney damage in animals both by oral and intravenous administration.

The Monoalkyl Ethers of Ethylene Glycol have the trade name of "Cellosolve". Cellosolve itself (the monoethyl ether), methyl cellosolve, butyl cellosolve and their

acetates are good solvents for cellulose ethers and esters. Methyl cellosolve and cellosolve acetate are also used for special high gloss lacquers, and methyl cellosolve has been specially applied to the "fused collar" industry in America, where the collars are dipped in a solution of methyl cellosolve and finished under heat and pressure. The toxic hazards of these compounds are not in normal conditions great. In animals butyl cellosolve has proved the most toxic, causing symptoms of kidney inflammation (WERNER, MITCHELL et al., 1943) and increased fragility of the red blood corpuscles. Its toxic action in this respect has been attributed to its metabolite butoxyacetic acid, which has been found in the urine of animals and human beings exposed to butyl cellosolve, and in animals has a greater haemolytic effect than butyl cellosolve itself (CARPENTER, POZZANI, WEIL et al., 1956).

Methyl cellosolve is reported to have caused a toxic effect, unique in this series, upon the central nervous system, as well as upon the blood picture. This condition, called a "toxic encephalopathy" occurred in the fused collar industry, the symptoms being described as a change of personality from liveliness and intelligence to dullness and apathy (GREENBERG and MAYERS, 1938; PARSONS and PARSONS, 1938).

The difference in toxicity of these chemically related compounds is most probably to be explained by differences in their metabolic progress, depending partly on the presence of primary, secondary or tertiary alcoholic groups and their relationship to each other. Where primary alcoholic groups occur, oxidation might result in formation of the corresponding acids, which may exert their toxic action by inhibiting enzyme systems. Some of the compounds undergo conjugation with glucuronic acid, but only if they contain six carbon atoms, and even then the conjugation is less than 10 per cent. Ethylene glycol, for example, is oxidized through oxalic and glycollic acid to CO_2 and water with practically no conjugation (GESSNER, PARKE and WILLIAMS, 1960) while propylene glycol, considerably less toxic, is metabolized, to the extent of two-thirds of the dose, to lactic acid; this is then oxidized to CO_2 and water through the tricarboxylic acid cycle. Undoubtedly the predilection for the kidney of those members of greatest toxicity is associated with their metabolic formation of oxalic acid in the body and the tendency of this to block the tubules of the kidney during their efforts to eliminate it. It is also believed that other intermediate metabolites, particularly glyoxal, may be involved.

CARBON DISULPHIDE

Carbon disulphide has long been used as a solvent in the rubber and viscose industries, and the toxic effects of chronic exposure have been more widely recognized than its acute narcotic effect.

The symptoms of chronic CS_2 intoxication are predominantly nervous, with peripheral effects in the form of polyneuritis, and central, with psychic abnormality and mental derangement. Of recent years, much attention has also been focussed on a possible long-term effect—the development of arteriosclerosis, sometimes associated with kidney lesions, at a relatively early age but with a latent period of about twenty years.

In cases of this kind, described by VON RECHENBERG in 1957, the arteriosclerosis is found in the arteries and arterioles especially of the brain, but also of the peripheripal muscles, where it appears as a calcification of the medial coat. Hyper-

tensive kidney injury, with high blood pressure, some albuminuria, slight micro-
haematuria and a raised residual nitrogen have also been observed—the condition
designated as "CS_2 glomerulosclerosis".

The whole late syndrome, consisting of encephalopathy, hypertensive kidney
injury and medial sclerosis does not always present itself in the complete form;
individual cases may only show some aspects. Diffuse vascular encephalopathy
may be present without hypertensive nephritis, and any or all of the manifestations
may be those of a general vascular toxic effect of CS_2 or its metabolites.

It was shown in 1943 (MCKEE, KIPER *et al.*) that after short-term exposures even
of high concentrations, CS_2 is rapidly removed from the body on cessation of ex-
posure, and the amount retained by the body is normally small. With continued
exposure on the other hand only 10 to 30 per cent is excreted by the lungs and about
1 per cent in the urine, the remaining 70 to 90 per cent undergoes metabolic trans-
formation in the body.

The actual mechanism of this transformation is not completely understood, but it
appears to be related to the binding of the retained portion with groups of sub-
stances containing a nitrogen atom—peptides, protein and amino-acids. The
enzymic reactions, especially with the amino-acids, produce dithiocarbamates which
can be further decomposed by the desulphydrase system of enzymes, liberating
CS_2. This may then be rapidly oxidized to H_2SO_4 and excreted in the urine as sul-
phate. Some observers (STRITTMATTER, PETERS *et al.*, 1950) have stated that in ani-
mals exposed to CS_2 there is in fact an increased excretion of inorganic sulphate.
The dithiocarbamates may possibly give rise ultimately to isothiocyanates. Dithio-
carbamate acids contain relatively strong acid sulphydryl groups, and the serum of
guinea pigs exposed to inhalation of CS_2 has shown an increase of such groups, which
have also tended to be statistically higher than normal in viscose workers exposed to
concentrations of 200 ug/l. (SOUCEK and MADLO, 1956).

These facts indicate that the intramolecular reaction of CS_2 with albumen causes
a marked alteration in the molecule.

The liver is undoubtedly an important organ in the metabolism of CS_2, and some
recent investigations in Germany (MICHALOVA *et al.*, 1959) have suggested that
signs of its capacity for detoxication of CS_2 are shown by changes indicating a
disturbance of capillary permeability. This endothelial disturbance, present
probably in the general arterial system, and sometimes, as already remarked,
associated with premature arteriosclerosis, is not however considered to be its direct
cause.

Other factors such as hyperlipaemia, and especially an increase of cholesterol in
the blood have also been held responsible. Cholesterinaemia is certainly a feature
of CS_2 intoxication in animals and is believed to be another manifestation of
altered bodily metabolism, intricately bound up with the enzyme systems, more
especially with the metal complexes required as activators. Alkaline phosphatase,
for example, requires zinc and magnesium ions, and the urinary excretion of both
has been found increased in animals chronically poisoned with CS_2, the alkaline
phosphatase activity being at the same time decreased.

The chain of events in this metabolic disturbance appears to be that of a chelating
effect by the dithiocarbamate and thiozolidone resulting from the reaction of CS_2
with free amino groups in the body. This chelation results in the polyvalent metal

ions being prevented from performing their necessary function in normal cell metabolism.

An interesting aspect of this hypothesis is the way in which it can be linked up with the nervous lesions of CS_2 toxicity. These, as we have seen, may be either central or peripheral in origin. Histological examination of the nerve tissues of animals subjected to prolonged and severe exposure to CS_2 have revealed degenerative changes in the cells of the brain and spinal cord amounting to almost complete destruction and loss of function. In the brain and spinal cord copper is normally present as a structural part of cytochrome oxidase and co-enzyme A dehydrogenase. Copper is also known to be tightly bound to the thiocarbamate groups, and in animals with severe pathological lesions of the brain and spinal cord the copper content of these tissues is about half the normal.

Thus it appears that the specific toxic action of CS_2 on the nervous system may be directly associated with its remarkable metabolic behaviour in this respect (COHEN, SCHEEL et al., 1959).

It must be agreed that the complex subject of toxicity as related to metabolism is of absorbing interest and importance in its far-reaching possibilities of solving some of the as yet unsolved problems of industrial toxicology.

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THE MEASUREMENT OF LEAD ABSORPTION
IN INDUSTRY*

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Abstract—Clinical examinations were carried out on 540 workmen in an industry using metallic lead. At the time of the examination specimens were obtained for lead in blood, lead in urine, urinary coproporphyrin, punctate basophilia and haemoglobin estimations. The results of these tests are compared with each other and with an overall assessment of the degree of lead absorption of each man.

Much of the data used in this communication was presented by the authors at the Thirteenth International Congress on Occupational Health, New York, 1960, in a paper entitled "Relative Significance of Tests for Industrial Lead Absorption and Poisoning Determined by Field Surveys".

The widespread use of lead in industry, historically and today, has resulted in a very large, although not disproportionate, amount of published information concerning industrial lead poisoning. In spite of, or possibly because of, this volume of work by doctors and hygienists, there is still some disagreement concerning the best criterion upon which to base control measures in the lead-using industries. Although biological measurements are commonly accepted as the basis of control, there is considerable disagreement as to which biochemical change is most important. Punctuate basophilia, haemoglobin, the lead content of blood and urine, quantitative and qualitative coproporphyrins, and many combinations and variations of these tests all have their champions. In many instances medical examinations may be carried out instead of, or in addition to, such tests, and such an examination may range from a cursory inspection for the Burtonian line, with a minimum of questions regarding past health, to a full medical examination in a properly equipped surgery.

Much of the disagreement between workers in this field has been caused by the existence of two concepts of the effect of lead upon man, lead poisoning, or clinical plumbism, and lead absorption. Because of the varying susceptibility in men to lead, signs of high lead absorption are not necessarily accompanied by the symptoms of plumbism, and although in many groups of lead workers it is possible to find evidence of high absorption without any cases of plumbism, this in no way affects the responsibility of those of us engaged in occupational hygiene to follow any evidence of high lead absorption by engineering or disciplinary action to remove the cause.

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* This paper is based, in part, on data originally published in *Industrial Medicine and Surgery,* 29:11, pp. 534-39, November, 1960.
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The final answer to the lead problem in industry must, of course, be based upon engineering control of such efficiency as to reduce the amount of lead dust, or fume, in the working environment, to well below the conventional "allowable concentrations". Even then, as now, clinical observation, supported by laboratory tests will be necessary to protect the men from human or engineering failure, together with environmental sampling to detect such failures, if possible, before they result in excessive lead absorption by the workmen. In some industries this is the case today, with the combination of works' doctor, and hygienist giving almost complete protection to the men. However, in many factories little or no advice is available until cases of plumbism arise. At this stage, outside authorities investigate the working conditions, and improvements are made which in the fullness of time lapse and become forgotten until new cases of plumbism arise, and the cycle is repeated. The control of a lead risk in industry must be a continuous process, and even if the measurements are made by an outside body, the responsibility for action and control must be firmly fixed at factory level. If the measurements upon which control is based can be made by the factory staff as a routine procedure, this responsibility cannot be escaped or ignored. Thus the best criterion of lead absorption for use in a factory may not be the best from the academic viewpoint. It must be suited to the particular factory and process concerned. The use of various biochemical tests in industry has been discussed by WOOLF (1958), who also described a simple technique for coproporphyrin estimation similar to that used in this investigation.

The investigation now reported was not designed to show the academic value of the various criteria as regards clinical plumbism, but rather to illustrate the relationships between them when measured in a working population exposed to a wide range of atmospheric lead concentrations. The men were working at the time of the investigation, and no cases of clinical plumbism were observed. The data obtained may therefore differ from those obtained from cases of plumbism treated in hospital after their removal from further exposure to lead.

The laboratory tests chosen for the investigation were the simplest of their kind, such as could be used in a factory. The urine samples for lead and coproporphyrin estimations were spot samples taken under conditions designed to give minimum contamination. Although 24-hr samples, or a series of such samples, are preferable for the measurement of lead excretion, it is impossible, under factory conditions, to obtain genuine samples of this nature, with or without lead contamination, and particularly as a routine measure. Coproporphyrin measurements were limited to the semi-quantitative type. Punctate basophilia were counted under dark ground, starting at 1 PC/1000 R.B.C. Haemoglobin was estimated on the Haldane scale (100 per cent = 14·8 g per cent). These laboratory techniques are described in appendices 1–5.

Although continuous atmospheric sampling was carried out for two periods of two weeks during the course of the three months' investigation, the data were more useful in planning engineering control than as a measure of exposure, and are not included in this report.

The biological samples were obtained when the men were clinically examined by Dr. A. R. Thompson. The clinical assessment was made according to the classification of Fig. 1. Although such a grading may be criticized as regards the relative weightings, it is doubtful whether any attempt of this nature would receive universal

approval, and for our purpose it proved satisfactory. In all, 540 complete sets of data were obtained, each relating to one man at the time of examination.

METHOD OF CLINICAL ASSESSMENT FOR LEAD WORKERS

Grading Marks

 1 mark: No clinical evidence
 2 marks: Coincident peptic ulcer group (confirmed clinically or by X-ray)
 3 marks: Pyorrhoea-gingivitis group with indefinite gum pigmentation
 4 marks: Non-specific dyspepsia associated with vague abdominal pains and constipation
 5 marks: Pallor and lassitude associated with an haemoglobin 90% or below
 6 marks: Confirmed anaemia (haemoglobin 80% or less) with other supporting signs
 7 marks: Habitual constipation
 8 marks: Abdominal colic
 9 marks: Blue Burtonian line
10 marks: Neurological involvement

FIG. 1.

The analysis of these data presented difficulties. Statistical methods, although simplifying presentation, were not used because of the absence of any clearly defined groups, and of any single basic criterion with which to compare the others. For example, a man in the worst position as regards atmospheric lead could have received, by the correct use of his protective equipment, a lower exposure than many of the workmen in parts of the workshop remote from the main lead process. In addition, the large numbers of men at the lower levels of exposure, where estimations were least accurate, would have given an unjustified relationship between criteria, even assuming linear relationships. Finally, it was thought that the tabular and graphical form used throughout would be more readily appreciated by many of the people who have the responsibility for this work at factory level.

Figure 2 summarizes those biochemical findings which would normally be regarded as indicative of high lead absorption with relation to the clinical findings in

	No.	Percentage						
		Clinically positive	Cp^+	Pc^+	Pc^{+++}	Hb^+	Pb_B^+	Pb_U^+
Overall	540	19	24	48	7·6	1·9	17	26
Taken off lead work	15	87	67	93	47	20	80	67
High exposure, clinically negative	17	0	48	36	6	0	54	48
High exposure, clinically positive	17	100	60	72	18	6	48	72
Other clinically positive ..	70	100	26	44	7	3	30	19
Other clinically negative ..	421	0	20	47	6	1	10	23
Clinically positive > 5 ..	25	100	28	52	12	8	24	12

Clinically positive = > 2
Cp^+ = > Trace
Pc^{++} = > 1/1,000 R.B.C.
Pc^{+++} = > 3/1,000 R.B.C.
Pb_B^+ = > 80 μg. Pb/100 mls. blood
Pb_U^+ = > 150 μg. Pb/litre urine
Hb   = < 80%

FIG. 2.

various groups of workmen. It must be emphasized that a clinical grading of ≥ 2 does not imply clinical plumbism, but rather conditions which could be associated with lead, or other causes. For instance, in a population such as this, largely engaged on shift work, with wide variations in diet, constipation is not necessarily a result of lead absorption. The first line gives the overall distribution of positive findings. During the investigation, and before the results were studied, it became apparent that some men were showing signs of excessive lead absorption, and these were removed from intimate contact with the lead processes. The second line shows their data as that accepted for high lead absorption, with a high percentage of positive findings in each category except that for haemoglobin. The next two groups came from an area shown to have high atmospheric lead concentrations. Although fresh air hoods were supplied as protection against the lead dust, half of this group gave some clinical evidence suggesting lead absorption. However, in both clinically positive and negative halves there was a high proportion of positive laboratory findings, and the difference between the two groups was not well marked. The last three groups concern men who were not in the high exposure areas of the factory, and who were not removed from their work despite some indications of exposure to lead, presumably before the investigation. Dividing these into clinically positive and negative groups, it can be seen that the greatest difference is in the percentages with high blood lead values. Finally, if comparison is made between the highly exposed but protected and clinically negative group, and the group with lower exposure but positive clinical findings, it would appear that the tests used were more of an indication of exposure to lead, and therefore lead absorption, than of the effects of lead which could be observed clinically.

In addition to the laboratory tests described, white cell counts were performed on forty men who showed the greatest overall evidence of excessive lead absorption. The total W.B.C. and lymphocyte counts are shown in Fig. 3, in comparison with those from a control group. The increase in the lymphocyte count is well marked.

Comparisons between the laboratory tests are shown in histogram form. In Fig. 4, the population is divided into five groups, according to blood lead values. For comparison with lead in urine, for instance, the distribution of urinary lead values inside each group is shown. Similarly the distributions of punctate basophilia, coproporphyrin and haemoglobin are given. In each case there is a general relationship, but the difficulties that arise when discussing the validity of any one criterion can be seen. It is possible to have a high blood lead value with a low urinary lead, or low coproporphyrin, etc., and although in practice it is possible to use blood lead values for control of absorption, this does not invalidate other criteria, which may in turn be used equally satisfactorily.

The date for haemoglobin are shown in Fig. 5. Apart from those men with a very low haemoglobin, there appears to be little agreement with the other factors. This is undoubtedly due to the normal range of haemoglobin in such a population. A comparison between the lead workers and a control group from the same factory is shown in Fig. 6.

Although the finding of punctate basophilia in lead workers, either by itself or in association with haemoglobin, is successfully used as a criterion of absorption in some industries, the data shown in Fig. 7 suggest little agreement with the other signs of lead absorption except at the higher levels. This is possibly caused by the

variation of punctate basophilia that can occur during a day, as reported by
MINDEN, H. and OPITZ, N. (1957). We carried out a similar series of counts on
fourteen men, four times in one day. The results are shown in Fig. 8. It can be seen
that while some men gave quite consistent values, others gave variations outside
that which could be associated with counting error.
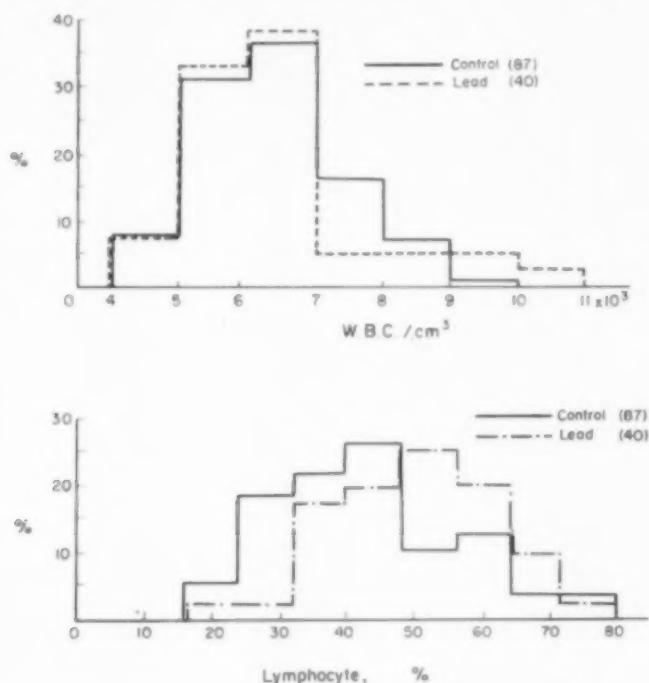
FIG. 3.

Coproporphyrin data were divided into two groups only, positive and negative,
because of the small numbers with strongly positive findings. They are shown in
Fig. 9.

The lead in urine data are of particular interest because of the widespread use
of urinary lead as a control measure. In practice this is often based upon a "spot"
sample of urine, because of the difficulty of obtaining uncontaminated 24-hr
samples as a routine at factory level. In order to observe the error resulting from
spot samples, one of the environmental sampling team collected his urine for
eleven days out of the thirteen during which he was in the factory. This subject
had no previous occupational exposure to lead, although while in the factory his
duties took him into the more heavily contaminated areas. The subject was new to
this type of work, and as such may have been affected by his change of environment.
The urinary lead data from this subject are shown in Figs. 10A and 10B. Fig. 10A
shows the total lead excretion, in each sample, and for each 24-hr period. For this
purpose, the urinary day was taken as from after the first morning voiding, and
including the first voiding of the next day. Fig. 10B gives the excretion of lead as
concentration in urine. It can be seen that during the first week his excretion was

FIG. 4.

FIG. 5.

Haemoglobin, %

Haemoglobin, %
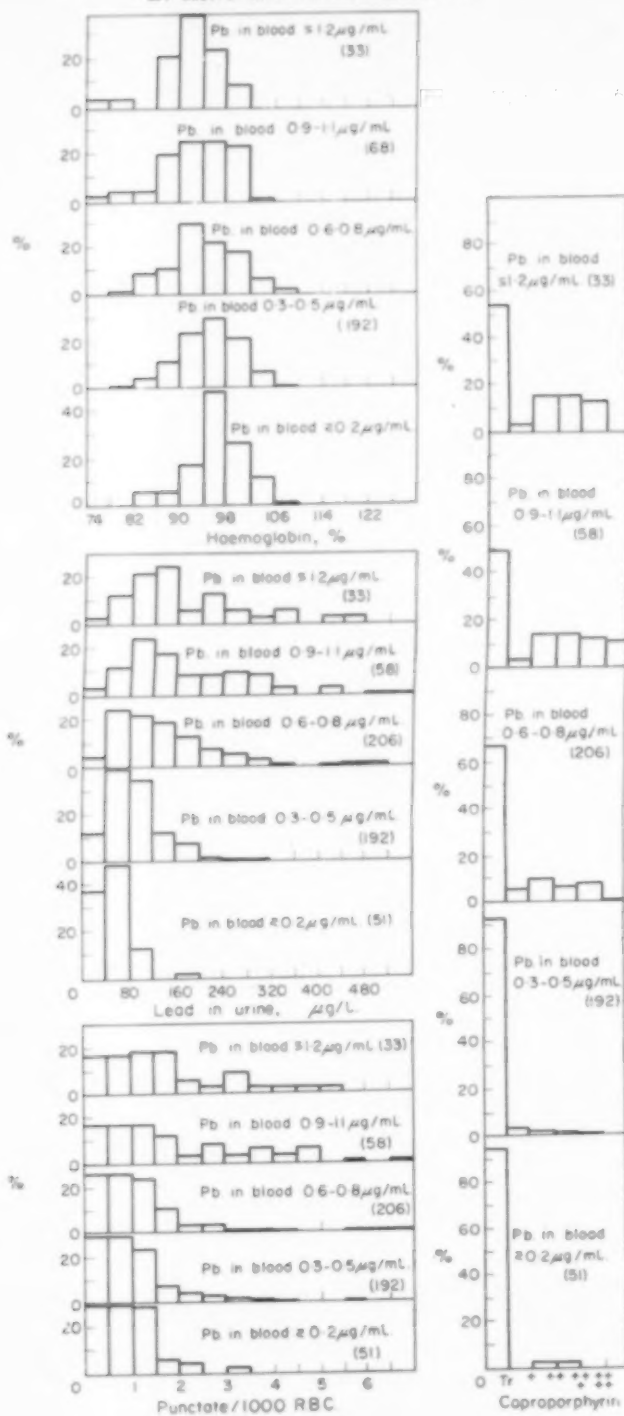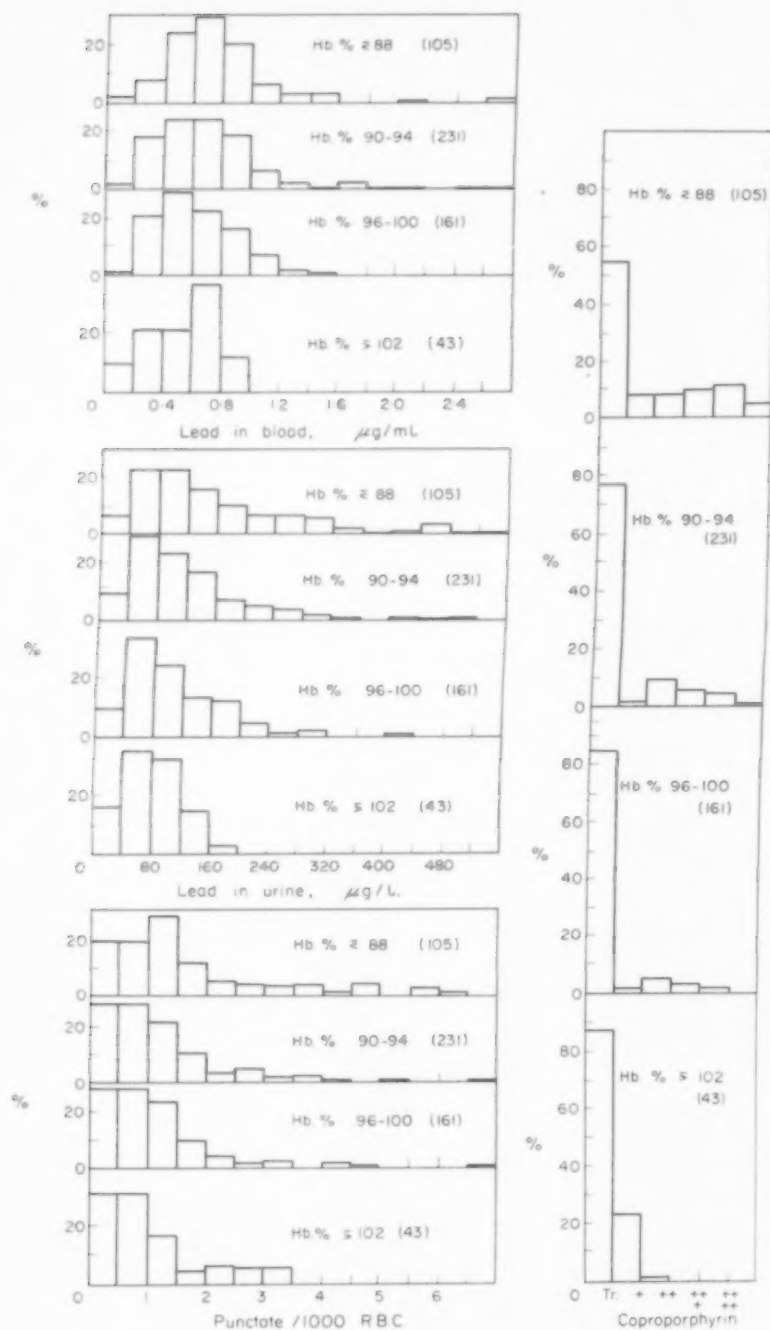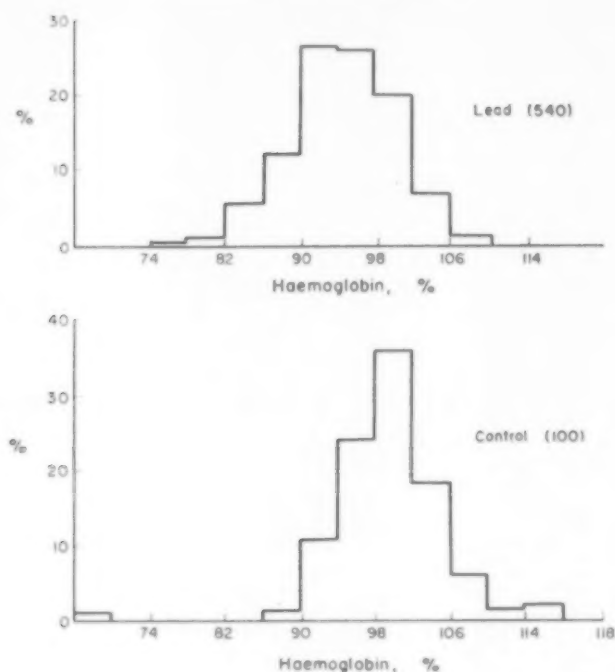
FIG. 6.

TABLE OF SERIAL PUNCTATE COUNTS PERFORMED ON FOURTEEN LEAD WORKERS

Subject	P.C./mill R.B.C.			
	9 a.m.	12 noon	3 p.m.	5 p.m.
A	1,200	1,400	1,200	1,600
B	1,100	900	300	700
C	Nil	1,000	700	1,400
D	800	1,600	600	700
E	2,700	1,200	100	700
F	2,700	4,000	1,200	1,600
G	2,000	2,100	3,500	2,900
H	4,000	4,200	3,800	4,500
I	1,600	700	2,000	1,900
J	2,300	2,500	1,900	1,400
K	500	1,200	1,300	800
L	400	100	500	100
M	1,800	1,600	1,700	2,700
N	3,200	3,900	2,200	5,400
Total ..	24,300	26,400	21,000	26,400

FIG. 8.
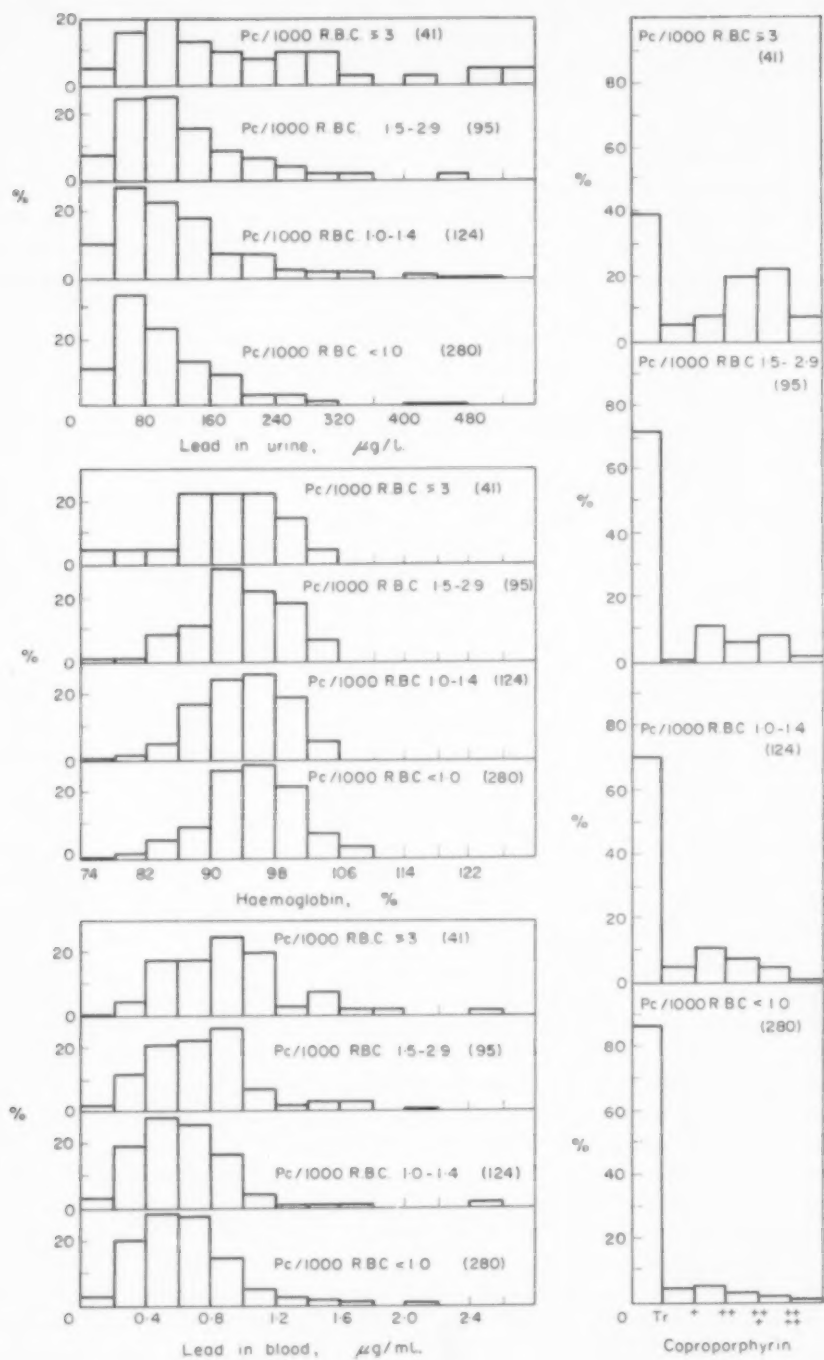
FIG. 7.

such as could be expected from a member of an urban population. Considerable quantities of lead appeared from the ninth day onwards. It is known that the subject consumed an unknown, but excessive, amount of spirits on the eighth day, and the decay in both the peak and average excretions after the ninth day suggests that the high levels of the ninth day were more possibly due to biological changes than his factory exposure. Whether the increase in lead excretion was caused by rapid mobilization of lead from the bones, or from the more recently deposited lead dust in the lung is not known. A more detailed study of this subject will be carried out, using both exposed and unexposed volunteers. Thus, while it is correct that considerable errors may arise from using spot samples of urine, these are only reduced by taking a 24 hr sample.

On this evidence, it would appear appropriate to question the man regarding his recent activities before taking the spot sample, and thus avoid the variations observed on this occasion.

The urinary data from the investigation are shown as Fig. 11. The coproporphyrin relationship is quite distinct, but this could be the result of the two estimations being performed on the same sample of urine.

When considering laboratory data concerning lead absorption, it is customary to make a final assessment based upon the overall picture, if available, rather than to rely upon a single factor. In order to express such an assessment quantitatively, it is necessary to place all of the laboratory tests upon a common scale. This was carried out as in Fig. 12, giving a grading of 0–4 for each test. The exact relationships between these tests are unknown, even if in fact simple relationships exist. The separations were therefore chosen on the basis of what might be considered significant in practice. In this way, any four tests gave a total laboratory grading of 0–16, and allowed the histograms of Fig. 13 to be constructed, comparing any one test with the other four.

As might be expected from the normal range of haemoglobin values, this criterion shows the least convincing relationship. Lead in blood shows a clear separation at the lower values, but not at the high ones, suggesting that the use of blood lead as a control measure will select almost all of those men with other laboratory findings, but will include others with otherwise little evidence of high absorption. The punctate basophilia show little agreement with the remaining tests except at high punctate levels. In general, the urinary lead presents a good overall picture, which is paralleled and rather excelled, by the coproporphyrin relationship to total grading. However, in both of these tests the lower values include men with high totals from the other tests, and the results should be interpreted with caution.

The relationships between the clinical findings and the laboratory tests are shown in histogram form in Fig. 14. Apart from the haemoglobin data, which were in fact taken into account during the clinical examination, the laboratory tests show typical loose relationships to the clinical findings except at the higher values. The overall laboratory grading appears to agree with the clinical assessment to a greater extent than the individual tests.

However, the purpose of this investigation was not to discuss the relative merits of the laboratory criteria for lead absorption, but rather to present data in such a way that within the limits of medical and laboratory facilities and experience a policy for the control of the lead risk may be planned and understood. Although the
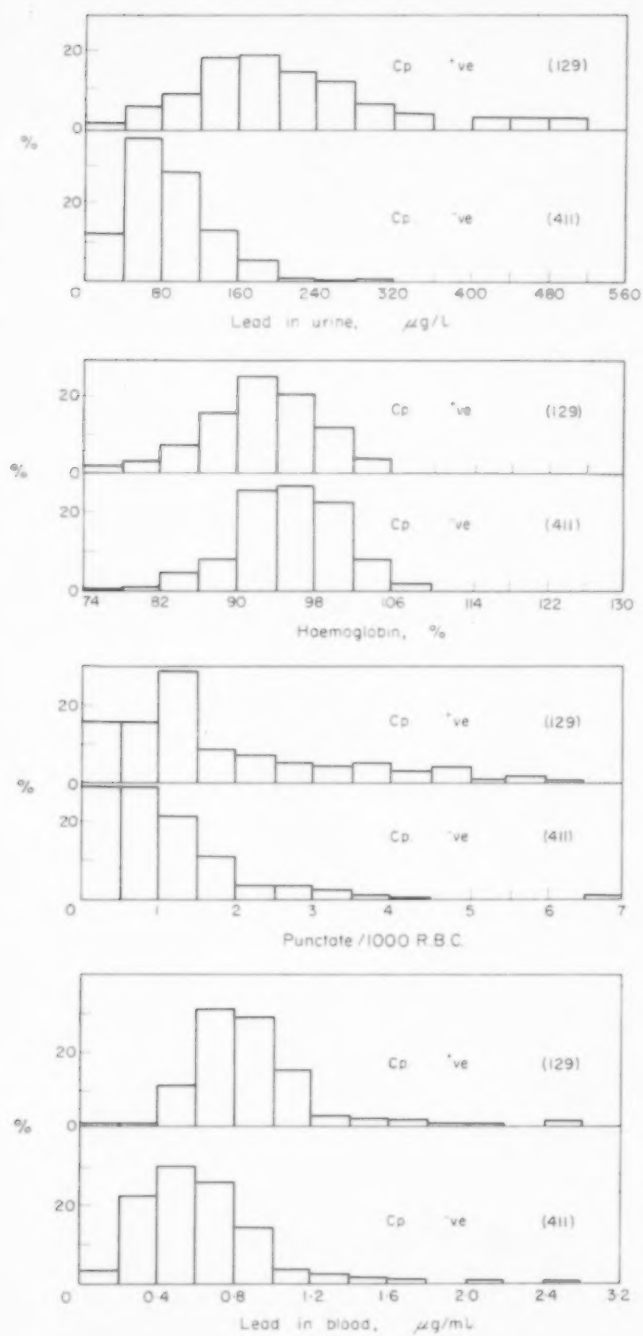
FIG. 9.
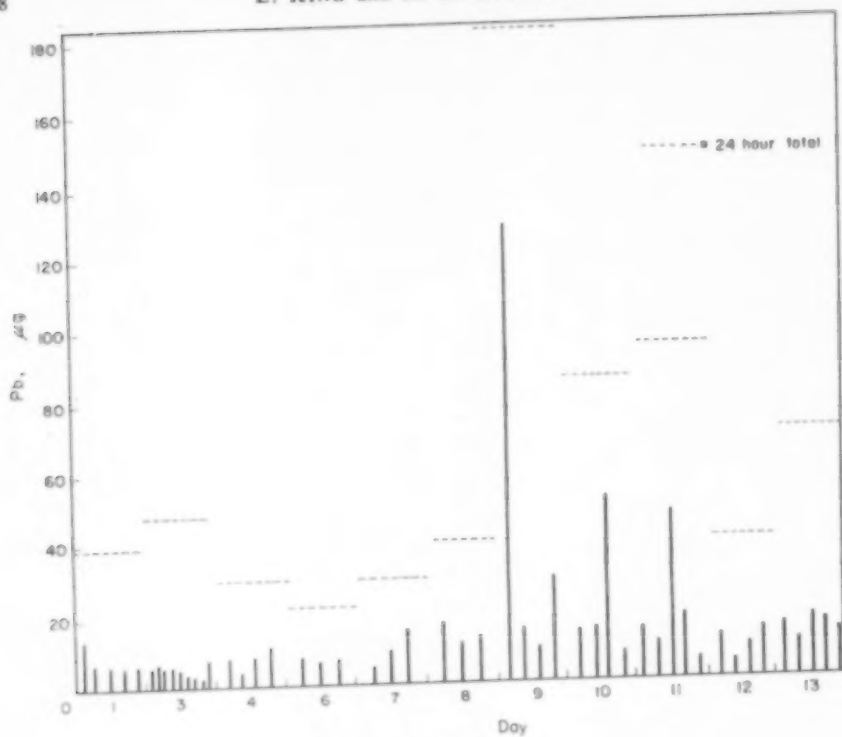
Fig. 10(a)
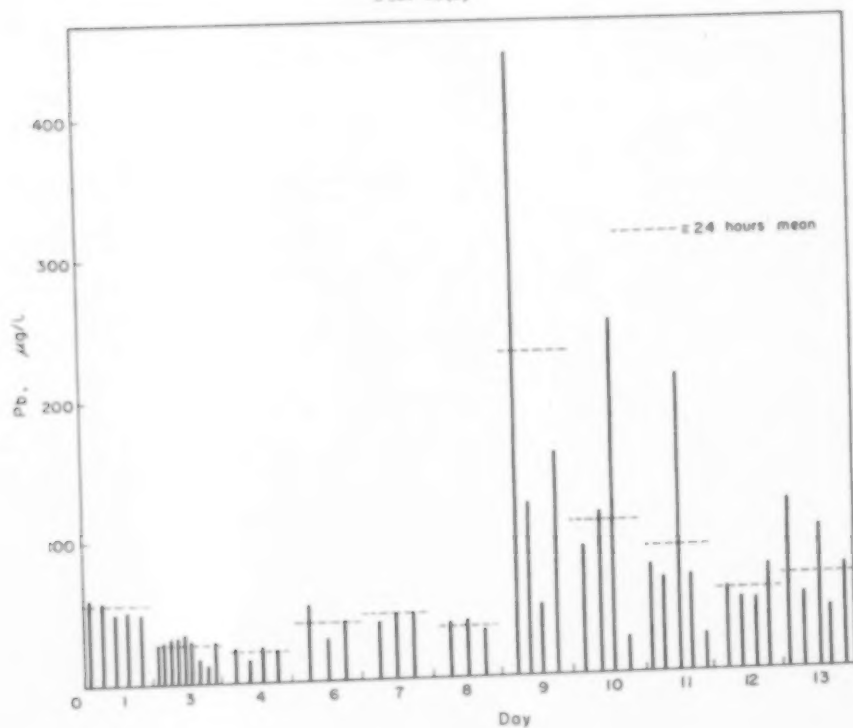
Fig. 10(b)
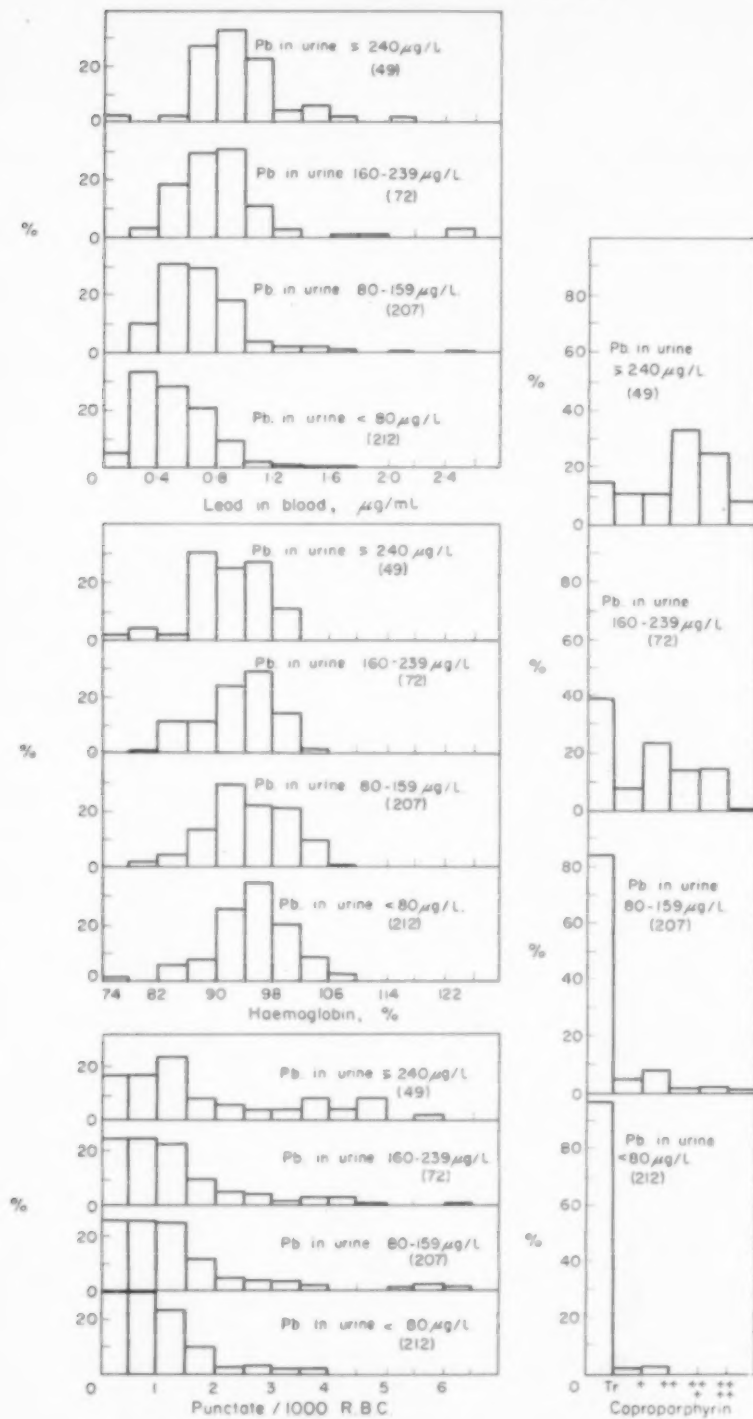
FIG. 11.

	0	1	2	3	4
Coproporphyrin ..	0	Tr⁺	++	+++	++++
Punctuate /1,000 RBC ..	0–0·9	1·0–1·4	1·5–1·9	2·0–2·9	>3
Blood μg. Pb/ml.	0–0·2	0·3–0·5	0·6–0·8	0·9–1·1	>1·2
Urine μg. Pb/litre ..	0–79	80–159	160–239	240–319	>320
Haemoglobin %	>102	96–100	90–94	84–88	<82

FIG. 12
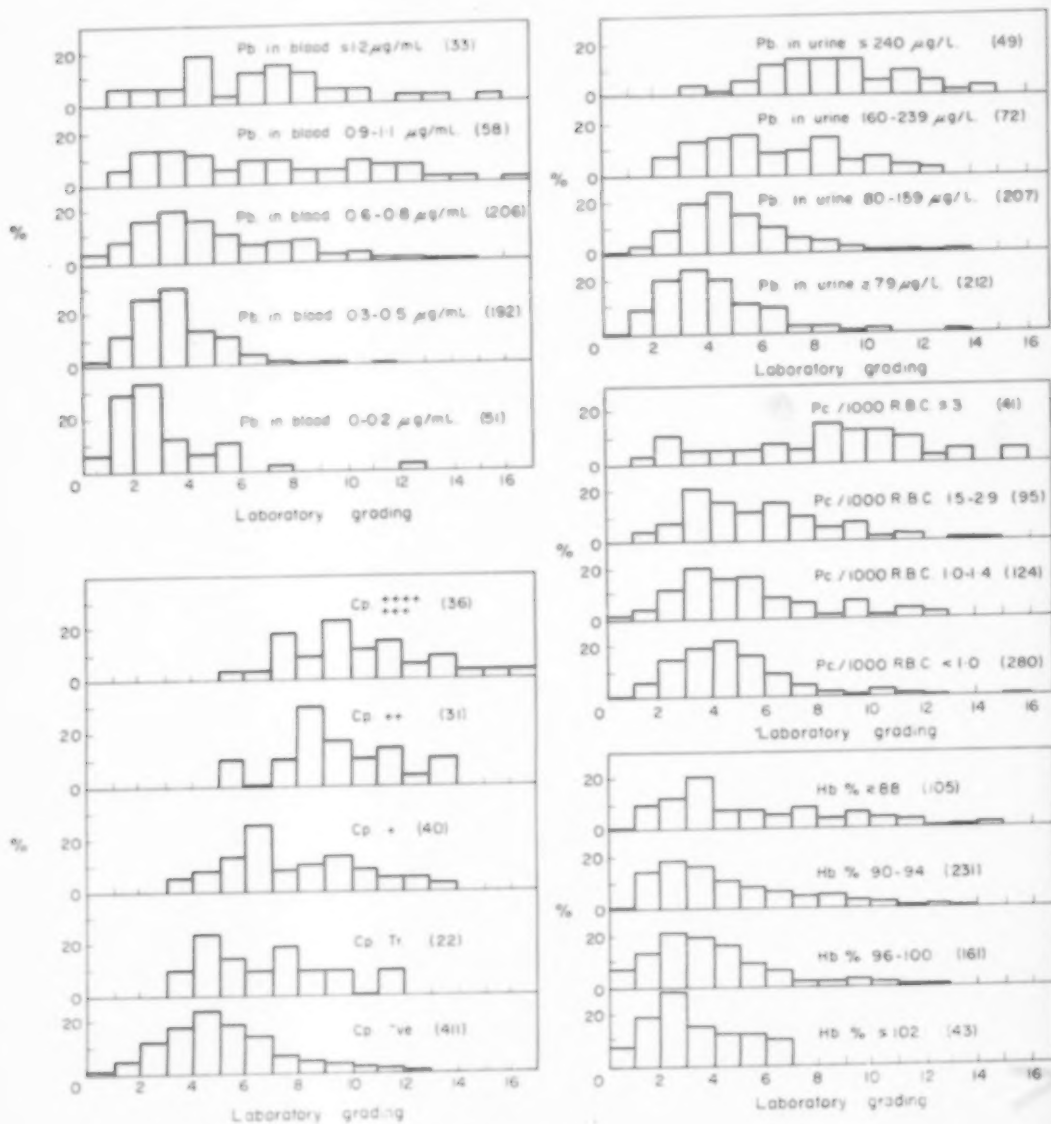
FIG. 13.
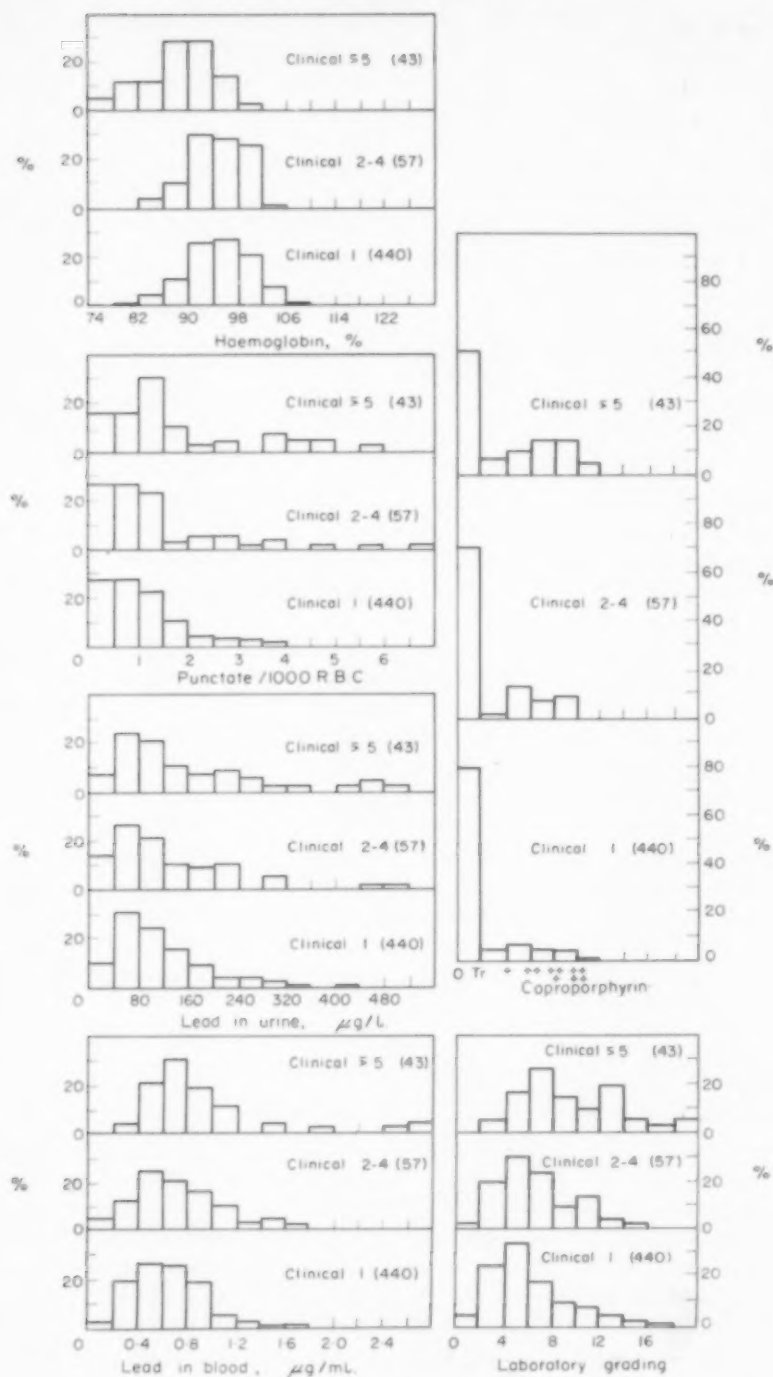
Fig. 14.

data suggest there is no complete single answer, a policy whereby any positive findings for the criteria chosen are followed by engineering action to find and remove their cause will be successful. Many industries operate lead control systems upon this basis, using different criteria.

The smaller factory, which often has engineering facilities, but no laboratory facilities and limited medical advice, may find the semi-quantitative coproporphyrin test of great value, provided it is used not only as a control for individual men, but also as a guide to controlling the environment which may be affecting men other than those first showing positive coproporphyrin values.

APPENDIX 1

Estimation of Lead in Urine

To 50 ml of urine in a 250 ml Pyrex beaker, add 25 ml concentrated nitric acid and 10 ml concentrated perchloric acid. Heat on a hot plate at about 280 °C until just dry. Add concentrated nitric acid drop-wise as necessary towards the end of drying to remove any brown coloration. Remove from hot plate and allow to cool.

Add 100 ml deionized water to the residue, and heat to obtain solution. Cool, and transfer to separating funnel. Add 5 ml concentrated ammonium hydroxide (880), 3 ml per 50 per cent ammonium citrate solution, and 10 ml of a buffer solution consisting of 3 ml 50 per cent ammonium citrate solution, 10 ml concentrated ammonium hydroxide (880) and 30 ml 10 per cent potassium cyanide solution, made to one litre with deionized water.

Extract the sample with 20 ml chloroform and 0.2 ml dithizone (0·1 per cent in chloroform). Wash the extract three times with 20 ml of a wash solution consisting of 10 ml 10 per cent potassium cyanide and 10 ml ammonium hydroxide (880), made to one litre with deionized water. Add a 12·5 cm filter paper to absorb residual water, and measure the absorption of the chloroform/lead dithizonate solution at 525 mμ. Convert to lead concentration in urine from a prepared calibration curve.

APPENDIX 2

Estimation of Lead in Blood

To 2 ml blood, in a graduated boiling tube, add 5 ml concentrated nitric acid and reduce to about 2 ml volume by boiling. Cool, and add 3 ml concentrated perchloric acid, and 1 ml concentrated sulphuric acid. Boil until fumes of sulphuric acid are observed. Cool the sample, make up to about 10 ml with deionized water, add 3 ml. 50 per cent ammonium citrate solution, make up to about 25 ml volume with deionized water then add 5 ml ammonium hydroxide (880), 10 ml of buffer as described in Appendix 1, and continue as in Appendix 1. Normally for blood specimens the final washing must be performed four times, instead of thrice as for urine specimens.

APPENDIX 3

Coproporphyrin Estimation

To 5 ml freshly voided urine, in a stoppered test tube, add 0·2 ml 3 per cent hydrogen peroxide solution, 1 ml glacial acetic acid and 3 ml ether. Shake gently, release pressure, and place in a light-proof box overnight. Observe the red fluorescence under ultra violet light, and grade the specimen O − + + + + by degree of fluorescence.

APPENDIX 4

Haemoglobin Determination

Take 0·05 ml blood, and make up to 9 ml volume with 0·4 per cent ammonium hydroxide. Measure absorption on a colorimeter, using a standard filter (EEL 404), and convert the reading to haemoglobin per cent to the nearest even number from a prepared calibration graph.

APPENDIX 5

Punctate basophil counts

Make a thin blood smear on a slide of 0·8–1·0 mm thickness, fix for about one minute in methyl alcohol, allow to dry and stain for 30 sec in Sellars stain (1 g methylene blue, 6 g sodium bicarbonate in 100 ml deionized water). Wash in tap water until the slide is a sea green colour.

Using a dark ground condenser and an Ehrlich eyepiece set to a 6 mm square, count the punctate cells in 10 consecutive fields. (Although in counting, the punctate cells are classified as large, medium, small, very fine or polychrome according to the size of the intra-cellular structure, this differentiation is for further reference on an individual case, and normally only the total count is given.) Close the eyepiece to a 2 mm square, and count the R.B.C. in this square. Repeat both counts five times on different parts of the slide, to give a punctate count of 50 large fields and an R.B.C. count of 5 small ones. Calculate punctate/1000 R.B.C.

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AN INVESTIGATION INTO THE EFFECTS OF EXPOSURE TO AN OIL MIST ON WORKERS IN A MILL FOR THE COLD REDUCTION OF STEEL STRIP

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Read at a Scientific Meeting of the BOHS held in London on
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Abstract—Volunteers who had been exposed intermittently to a mineral oil mist for periods ranging from 9 to 18 years were medically examined. There was no history of lipoid pneumonia, focal pneumonia, bronchitis, gastric disorders, dermatological conditions or diseases of the ears, nose and throat. The only possibly significant finding was that radiological examination of the chest showed increased linear striations in the lung fields in twelve cases. The oil was present as droplets, 70 per cent of which were 0·8 to 1 μ in diameter, and the maximum concentration noted during the investigation was 9·0 μg/l.

DURING the cold reduction in a 3-Stand Tandem Rolling Mill of coils of hot rolled strip steel, it was noticed that a certain amount of oil was carried into the atmosphere from the evaporation of some of the water coolant used in the process of rolling. In view of the possible hazard to the health of those employed in the vicinity of the mill it was decided to investigate the matter.

THEORETICAL APPRECIATION OF POSSIBLE ILL-EFFECTS

Consideration of the problem and study of what literature was available concerning human exposure and animal experiments suggested the following possibilities:

(a) Pulmonary–lipoid pneumonia, increased liability to develop focal pneumonia, bronchitis, long term fibrotic changes and carcinoma.

(b) Gastric—hyperplastic gastritis due to ingestion of oil following filtering in the naso-pharynx.

(c) E.N.T. conditions—rhinitis, sinusitis, pharyngitis and laryngitis.

(d) Dermatological—dermatitis and oil acne.

DESCRIPTION OF THE PROCESS

Coils of hot rolled strip steel which had been pickled in sulphuric acid, washed with water and then covered with a coating of mineral oil were brought from the Pickling Department by tractor to the feeding end of the 3-Stand Tandem Mill. This mill consisted of a 3-Stand train of rolls, each pair of rolls following the other in line. The strip width varied between 21 in. and 48 in. and was given a total reduction in the three stands of between 40 per cent and 60 per cent. The average speed of the Mill was: No. 1 Stand 300 ft/min; No. 2 stand 520 ft/min; and No. 3 Stand 640 ft/min.

The cold reduced strip was recoiled at the exit of the mill and taken by tractor to the Coil Cut-Up Line where it was sheared into sheets. The sheets were removed from the Line by Ross Carrier.

An overhead crane was available for use as required on the Mill and Cut-Up Line.

HEAT DEVELOPED DURING ROLLING AND ITS CONTROL

The heat produced during the reduction was controlled by the use of a water coolant consisting of a 4–8 per cent oil in water emulsion and this mixed with the thin coating of oil applied to the coil before rolling. There was a circulating system of 8000 gal and the rate of flow was 400 gal/min.

The following temperature readings were obtained:

(a) *Water coolant*
To Mill   ..   ..   75 °F
From No. 2 Stand   ..   ..   145 °F
From No. 3 Stand   ..   ..   195 °F

(b) *Strip itself*
Between 1 and 2 Stands ..   ..   125 °F
Between 2 and 3 Stands ..   ..   215 °F
Between 3 to Reel   ..   ..   125 °F

(c) *2 in. above Strip while rolling*
Between 1 and 2 Stands ..   ..   90 °F
Between 2 and 3 Stands ..   ..   175 °F
Between 3 to Reel   ..   ..   95 °F

(d) *Rolls immediately after rolling*
No. 1 Stand   ..   ..   ..   140 °F
No. 2 Stand   ..   ..   ..   130 °F
No. 3 Stand   ..   ..   ..   150 °F

COMPOSITION OF ROLLING OIL

The oil was supplied by Mobil Oil Company Limited under the trade name of PROSOL 1A. It consisted of about 85 per cent of a naphthenic spindle oil with petroleum sulphonates and rosin soaps acting as emulsifiers and with a small proportion of cresylic acid as a disinfectant.

OIL DISTILLATION TEST

At 160 °F the first volatile compounds were observed.
At 180 °F the first drop of distillate came over, and
At 200 °F 0·80 per cent distillate was obtained.

At 200/210 °F a white vapour was given off and this, which had a pungent and unpleasant smell, solidified in the condenser.

On further heating the oil to 225 °F the solidified portion in the condenser was cleared by the issuing vapour.

ESTIMATION OF OIL IN ATMOSPHERE

Samples were collected through a 4 in. diameter glass funnel attached to a length of ¼ in. diameter glass tubing into distilled water contained in a filter flask of

2000 ml capacity by means of a suction pump working at a rate of approximately 1 ft³ per minute, using a gas meter to measure the total volume.

At the conclusion of the test any oil adhering to the funnel and tubing was washed into the flask with ether. The contents of the flask were transferred to a separating funnel, washing the flask a few times with small quantities of ether. The water layer was removed and the ether solution transferred to a small tared flask. After the evaporation of the ether the oil was dried to constant weight in the air oven at 105 °F.

Sampling points

A. At the feed end of the mill, 3 ft to the side of the strip at a height of 5 ft.
B. On top of the mill structure between Stands 2 and 3.
C. Midway between Stands 2 and 3, approximately 3 ft to the side of the Strip at a height of 5 ft.

Sampling Point	Conditions of Test	Mill Data	Oil (μg/l)
A	Continuous for 4 hr Total volume 288 ft³	Cooling system operating	2·15
A	Continuous for 5 hr Total volume 360 ft³	Cooling system off	0·96
A	Continuous for 5 hr Total volume 360 ft³	Cooling system operating	0·78
B	Continuous for 24 hr	Cooling system off	7·00
B	Continuous for 4 hr Total volume 206 ft³	Cooling system operating	5·27
B	Continuous for 5 hr Total volume 257 ft³	Cooling system off	7.50
B	Continuous for 5 hr Total volume 257 ft³	Cooling system operating	2·20
B	Continuous for 5 hr Total volume 257 ft³	Cooling system operating	6·32
C	Continuous for 3 hr 15 min	Cooling system off	9·00
C	Continuous for 5 hr Total volume 350 ft³	Cooling system operating	1·79
C	Continuous for 5 hr Total volume 360 ft³	Cooling system operating	2·45

A further sample taken intermittently over a period of 3 hr about one foot above coils still hot from rolling gave a reading of 23·50 μg of oil per litre.

SIZE OF OIL DROPLETS

Examination of the oil droplets collected on a slide held in the steam rising from the rolling process showed that 70 per cent of the droplets measured 0·8 to 1 μ in diameter.

MEN EXPOSED TO THE ATMOSPHERE IN THE AREA AROUND THE ROLLING MILL

The total number of men regularly exposed in varying degrees to the atmosphere in the area was 28 per shift.

The mill was manned by a crew of nine men, four of whom were on the feeding end of the mill, one at the exit end of No. 1 mill, two at the exit end of No. 3 mill and two of whom relieved the other operatives. In addition there were two fitters, a recorder, a machine cleaner, a crane driver, two crane slingers and a tractor driver in the mill area.

The Coil Cut-Up Line had a crew of six men. Also around the unit were two fitters, a recorder, one tractor driver and one Ross Car driver. The crane driver mentioned in relation to the mill also serviced this line.

All those exposed, with the exception of Managerial Staff, were working on a 3-shift basis doing a 50-hr week. Each man had 21 days' holiday a year, including in this figure the statutory holidays.

VOLUNTEERS FOR INVESTIGATION

Nineteen volunteers were interviewed regarding their occupational histories, medical histories and present symptoms and asked for their personal observations regarding conditions of work. They then had a general physical examination including X-ray of the chest.

The volunteer group comprised eight operatives from the Cut-Up Line, six operatives from the Mill, three crane drivers, one tractor driver and the Mill Superintendent.

OCCUPATIONAL HISTORIES

The ages of the volunteers ranged from twenty-seven to fifty-five. The length of exposure ranged from nine to eighteen years, eight men having started when the Mill and Cut-Up Line were run-in eighteen years previously.

Two men had worked in a coal mine, one for nine years and one for two years. One man had been a baker for twenty years. Otherwise nothing relevant to the investigation was disclosed.

MEDICAL HISTORIES

(a) *Pulmonary Conditions*. Fifteen gave a clear history, three gave a history of pneumonia prior to working in the area and one volunteer had chronic bronchitis which had first appeared eight years prior to working in the area.

(b) *Alimentary conditions*. Fifteen gave a clear history. Two gave a past history of nervous dyspepsia, in one case related to domestic worry and in the other to work as a baker. One gave a history of jaundice and the other of chronic constipation leading to cancerphobia but relieved by laparatomy and appendicectomy.

(c) *E.N.T. conditions*. Sixteen gave a clear history, and the others have a history of otitis media, diphtheria and hay fever respectively.

(d) *Dermatological conditions*. Eighteen gave a clear history and one a history of seborrhoeic dermatitis.

PRESENT SYMPTOMS

Volunteers were asked direct questions concerning pulmonary and alimentary symptoms and in the course of their replies some referred to conditions which they had not mentioned in giving their medical history because symptoms were not severe.

Pulmonary symptoms. Twelve admitted to no trouble at all. Five had a mild chronic cough which they attributed to smoking cigarettes and one suffered from regular "colds on the chest". The chronic bronchitic mentioned above described typical symptoms.

Alimentary symptoms. Sixteen described their appetite as good or very good, one as fair, two as poor.

Eleven admitted to no symptoms at all and the other eight mentioned occasional trouble, using such terms as "heartburn", "wind", "water brash" and "indigestion". In no cases were symptoms severe enough for them to seek medical advice.

OBSERVATIONS REGARDING CONDITIONS OF WORK

Volunteers were encouraged to give their personal reactions to the atmosphere and all had some observation to make. Observations ranged from those of the man who said categorically "No ill effects" and went on to say that he had been used to Mills all his life, he expected them to be a bit "smokey" and that this was paradise compared with old mills, to those of the man who complained that conditions irritated his throat, nose and eyes, made him feel sleepy and gave him a deadly feeling in his stomach.

Eleven men complained that conditions made them feel sluggish or drowsy. Four men stated that their teeth went black unless they were cleaned regularly. Three men mentioned a slight cough caused by the atmosphere on certain occasions. Only one man, noted above, mentioned any gastric effect.

RESULTS OF CLINICAL EXAMINATIONS

Chest. Twelve appeared normal, four showed some abnormality of the thoracic cage, the chronic bronchitic showed typical signs, one case had a mild bronchial catarrhal condition and the other had visible veins on the front of the right upper chest.

Abdomen. Ten appeared normal, three showed epigastric mid line bulging on straining, one had bilateral inguinal herniation, one had a laparotomy scar, one had an appendicectomy scar, one had slight epigastric tenderness, one had hard masses in his upper recti muscles and the other was obese.

Weights. In twelve cases the weight on the day of examination was the highest known weight. In three other cases the difference between the weight on the day of examination and the highest known weight was 4 lb or less. In three cases weights were 9 lb, $10\frac{1}{2}$ lb and $11\frac{1}{4}$ lb below the highest known weight and in one case previous weights were not remembered.

Cardio-vascular system. Seventeen appeared normal, one had three sounds at the apex and the other an accentuated aortic second sound.

Blood pressure readings ranged from—98/64 to 154/98.

Ear, Nose and Throat. Nine appeared normal, seven had pharyngitis of varying degrees, one had active chronic otitis media, one had a healed perforation and one had a deviated nasal septum with obstruction.

Skin. Seventeen appeared normal, one showed Campbell de Morgan's spots on his chest and one comedones on his face.

X-ray of chest. All abnormalities however slight were recorded, but no imme-
diate further action in the volunteer's interest was considered necessary in any case.
Abnormal findings were classified as follows:

Thoracic cage—four cases; Diaphragm—five cases; Heart—three cases;
Hilar shadows—two cases; and Lung Fields—fifteen cases. The first three
groups contained no abnormality relevant to the investigation.

Comments regarding the hilar shadows were that there was a nodular shadow in
the area of the right lung root in one case and that the root shadows were slightly
enlarged in the other. Both were considered only slight abnormalities.

The lung fields were examined using normal films with similar degrees of penetra-
tion of men in the same age group for comparison. In twelve cases increased linear
striations were noted. In five of these cases and in three others a slight increase in
opacity was noted in scattered areas.

DISCUSSION

The maximum concentration of oil found in the atmosphere was $9.0\,\mu g$ per litre.
Oil distillation tests and measurement of rolling temperatures showed that the oil
was carried in an unchanged condition by the steam evolved in the rolling process.
It was carried in the form of droplets, 70 per cent of which had a diameter of 0.8 to
$1\,\mu$.

It was estimated that men were exposed to the maximum concentrations of oil,
intermittently, for about 2 hr a shift which would be equivalent to about 600 hr
a year. The volunteers had worked under these conditions for 9 to 18 years.

Neither reports of similar investigations nor human experimental work could be
traced in the literature.

LUSHBAGH, GREEN and REDEMANN (1950) in their experiments on mice, rats,
rabbits and monkeys used an automobile lubricating oil and a diesel engine lubricat-
ing oil in concentrations of 63 to 132 $\mu g/l$ with a droplet diameter ranging from
0.68 to $2.9\,\mu$ (average $1.16\,\mu$) and exposed the animals for periods varying from
100 to 365 consecutive days.

SHOSKES, BANFIELD and ROSENBAKM (1950) in their experiments on mice used
corn oil, peanut oil, codliver oil, liquid petrolatum and motor oil in concentrations
of 4333 to 57,100 $\mu g/l$ with a droplet diameter ranging from 2.1 to $2.7\,\mu$ (average
$2.5\,\mu$) and exposed the animals for a maximum of 108 hr over a period of 30 days.

The medical histories and clinical findings gave no evidence of obvious disease.

No volunteers developed pneumonia, either lipoid or infective, at any time during
their employment in the oil contaminated atmosphere. It therefore seems that the
filtering action of the naso-pharynx and the cellular and enzyme defence processes
in the lungs were capable of dealing with the amounts of oil inhaled. In this respect
the concentration of oil, the length of exposure and the intermittent nature of the
exposure must be considered.

One case of bronchitis, of eight years standing when commencing employment
in the area, had worked for twelve years with no apparent acceleration of the slow
deterioration commonly seen in the disease. No other cases of bronchitis were
recorded. Although in this investigation the oil used has proved non-irritant to
the trachea and bronchi, it must be noted that rolling temperatures are low enough
for the oil to be carried off unchanged; the oil distillation tests showed that at only

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slightly higher temperatures an irritating vapour was produced and there may be other industrial processes where this occurs.

No case of carcinoma of the lung was discovered. As the maximum length of exposure was only 18 years no final comment can be made on this finding.

The possibility of long term fibrotic changes in the lung is theoretically obvious and requires consideration in the light of the present findings.

Shoskes and his co-workers found that 80 per cent of all oil particles retained in the lungs of mice were $2 \cdot 5 \mu$ or less in diameter and the median diameter for particle retention in the alveoli $0 \cdot 8 \mu$. In their opinion results with mice could be applied to man.

Oil droplets penetrating into the lung are immediately phagocytosed and rapidly transferred into the pulmonary connective tissues and lymph nodes.

The monkeys in the experiments of Lushbaugh and his co-workers showed histological changes in the lungs differing in relation to length of exposure, the monkeys with the longer exposure showing fibroplastic changes in the connective tissues.

In the present investigation droplet sizes are such that penetration into the lungs and retention in the alveoli probably occur. Exposure has proceeded intermittently for 9 to 18 years. No volunteers have died, so no material has become available for histological examination. Clinically there is no evidence of pathological changes in the lungs. The X-ray findings show twelve cases in which it was considered that there were increased linear striations in the lung fields.

The X-ray changes were not marked and opinions differ regarding their causation. In this investigation are they of no significance or are they the early signs of a fibroplasia in the connective tissue of the lung produced by the retention of oil?

Lushbaugh and his co-workers found that most monkeys in their experiments died from a severe hyperplastic gastritis and this was considered by Lushbaugh to be indirect evidence that much of the inhaled oil was filtered out by the nasal passages and swallowed.

Two volunteers gave a history of gastric symptoms and in both cases they were clearly psychogenic. On persistent direct questioning eight mentioned some minor gastric trouble but in no case had it been severe enough to need medical attention. A high number, sixteen out of nineteen, stated that their appetites were good or very good. Clinical examination disclosed nothing significant. In only three instances were the weights below the highest known weight and only one of these was considered possibly significant. There was, therefore, no evidence of gastric irritation.

Although only one man mentioned that the atmosphere irritated his throat, seven men were found to have a pharyngitis of varying degrees. However, five of these were moderate or heavy cigarette smokers and the two non-smokers had the condition only to a mild degree.

No cases of occupational skin disease were found and this was consistent with findings in other comparable processes in the works.

Apart from the possibly significant radiological findings the investigation shows no evidence of occupational disease. Comparison with the animal experiments previously mentioned suggests that while in this case the amount of oil inhaled is small and can be dealt with by the body defences there may be other industrial processes in which the concentration is higher, the exposure longer and where harmful effects may be occurring.

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THE TRAINING OF OCCUPATIONAL HYGIENISTS

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IN the recommendations of the British Occupational Hygiene Society regarding the establishment of an occupational hygiene service on a national basis, it was emphasized that the success of such a service depended on the availability of a sufficient number of trained persons. The contents of the present paper suggest the type of training required for these people and the possible methods of carrying it out. Various titles have been ascribed to people performing this work, none of which are entirely satisfactory, but for present purposes it is proposed to call them Occupational Hygienists. It is intended to deal with the matter in a general way and not from the point of view of a particular industry. The Occupational Hygienist is not a specialist and should be able to practice his art in any place where people are at work. Persons employed by a particular organization will inevitably only deal with the hazards and circumstances arising within that organization; within the framework of a national service all industries and workplaces should be embraced. The Occupational Hygienist must therefore acquire a methodology and attitude which is comprehensive.

This paper deals primarily with Occupational Hygienists, not physicians using occupational hygiene in their practice (although there is definitely room for training in this respect), nor with people who are primarily chemists, physicists or engineers practising occupational hygiene and, again, there is room for training here. Skilled physicians, chemists and physicists would be needed as an integral part of the type of service in mind, but the bulk of the day-to-day skilled work would be carried out by Occupational Hygienists with the aid of suitable technicians.

The Occupational Hygienist would not only carry out and supervise investigations but also would have to interpret and advise on the results. He must therefore have suitable educational attainments giving him appropriate professional status. The minimum requirement would be a degree or equivalent qualification backed up by a course of training in the practice and principles of Occupational Hygiene.

The basic training of the person undergoing a course in Occupational Hygiene is important. It is difficult to decide whether he should be an engineer, physiologist, physicist, chemist or person with a general science degree, but on consideration it is doubtful whether it matters much as long as the training is in one of the practical sciences and gives a good insight into scientific method. This is paramount and should of course be inherent in the training of a graduate in any of the sciences quoted. His view should not be narrow and he must be able to see the interrelationship of the various disciplines so that he can use techniques

from each or all in order to carry out his essential purpose of studying the impact of the working environment on the working man and to influence this impact if it is found to be necessary.

It is likely that a person educated to degree level in an appropriate branch of engineering would be most suitable. He should have a reasonable knowledge of chemistry and physics and his dominant subject would be essentially related to Industry. This is an important point because the Occupational Hygienist must ultimately be familiar with all aspects of Industry and this is facilitated by knowing something at least about one of the parts. The chemist, physicist or physiologist with a purely academic background would be at a disadvantage in this respect. On the other hand if a chemist or physicist has acquired his degree or equivalent qualification while working in Industry this would not be pertinent; but, under these circumstances, it is likely that his professional life is already planned and transference to a different type of work would not be viewed favourably by himself or his employers. Even so, consideration must be given to recruiting this type of person as a large amount of the technological training in this country is carried out under these circumstances. The physiologist would have a marked advantage on the other side of the working man$\rightleftharpoons$working environment equation; he would also have physics and chemistry to a similar level; but his industrial experience would be negligible and, unless he was prepared to become also a first class mechanical engineer, he would have only limited competence when giving advice on environmental control measures. The person with a general science degree would need to acquire a knowledge of engineering and physiology but would perhaps be the ideal type of candidate. Industrial experience would have to be gained subsequently. Much would depend on his main subjects and if physiology was a subsidiary subject, he would have a very good background. SAYERS and BLOOMFIELD (1936) recommended graduation in chemical engineering as one of the minimum qualifications for the Occupational Hygienist. While this form of training would appear eminently suitable there are only relatively few in this country, and at present they are in very great demand by a number of different industries. Perhaps in between five and ten years' time the demand will be more or less satisfied by increased output from the universities and other sources and there will be scope for recruitment into occupational hygiene.

To reiterate what was said previously, it would seem to matter little what the exact contents of the undergraduate training are as long as a good scientific approach on a broad basis has been obtained, and as long as the specific post-graduate course in Occupational Hygiene is carefully planned and related to previous experience. It would, of course, be preferable if those undergoing instruction had the same or very similar educational backgrounds. A comprehensive course for a number of different disciplines would be unbalanced and uneconomical but it would probably be possible to permit exemptions in certain subjects according to the student's previous attainments. For instance, people with an engineering degree would be exempted from instruction in all but the specialized forms of engineering; a physiologist from the physiological work; and persons with a general science degree from those subjects in which they have graduated, apart from their special applications to Occupational Hygiene. Exemption from instruction would not include exemption from the practical and theoretical examinations.

SYLLABUS

Rather than consider the organization and duration of courses, whether they should be full-time or part-time, who is to give instruction, and whether some of the subject matter could not be used as an optional subject at the end of a degree course it would perhaps be better to outline the basic syllabus. When the requirements of this are appreciated it will probably be easier to discuss these other matters. The design and contents of the syllabus must naturally be related to the function of an Occupational Hygienist and if the function of an Occupational Hygienist is to practice Occupational Hygiene, he will be practising the science leading to the provision of a healthy and comfortable working environment. He will be responsible for creating and maintaining a harmonious interaction between working men and their working environment. His work is complementary to that of the industrial physician who has a similar function but with the emphasis on the man rather than the environment and, as medicine is practised today, more often on the sick man than the healthy man. Whether the general attitude within medicine will change and endeavour to anticipate dysfunction in hitherto healthy men is not our immediate concern, although it would serve the interest of everyone in Industry, if it did, and the employment of physicians with this view is essential to the success of any occupational hygiene service. It is suggested that a syllabus to cover the basic training of an Occupational Hygienist would include the following:

1st period
1. Basic physiology and biochemistry
2. Basic engineering
3. A revision of inorganic and organic chemistry
4. A revision of physics
5. A revision of mathematics to a necessary level
6. The structure of industry, industrial relations and industrial economics
7. Legislation relating to health and safety in industry
8. History of industrial health

2nd and 3rd periods
9. Applied physiology
10. Toxicology, including the examination and evaluation of biological material in relation to toxicology
11. Dust diseases, together with dust estimation and control
12. Heating and ventilating engineering and air-conditioning, together with heating and ventilating surveys
13. Illuminating engineering and lighting surveys
14. Noise, sound level measurements and audiometry
15. Ionizing radiations
16. Atmospheric pollution
17. Physiological and anatomical aspects of machine design
18. Statistics
19. Chemical and physical methods used in toxicology
20. Instrumentation and the maintenance of instruments
21. Laboratory technology, including glass-blowing and the improvisation of apparatus
22. The design of an industrial hygiene survey and the principles of sampling

Practical

(*a*) Laboratory work in relation to the above

(*b*) Visits to appropriate works and units

(*c*) A minimum period of a fortnight working with an existing occupational hygiene team, if this could be arranged.

Discussion groups and seminars would be an important part of the programme.

Each student would be required to write a full report on a practical exercise within a factory or workplace, if suitable places could be found, and each student should write a review of existing knowledge in a particular sphere of industrial hygiene.

ORGANIZATION AND DEVELOPMENT OF A TRAINING PROGRAMME

There are very few people in this country today who can be called Occupational Hygienists in the fullest meaning of the definition given previously. So small is the number that it provides little basis from which to expand and upon which to graft an educational system. Some physicians have a substantial knowledge of occupational hygiene and of what is desirable in an Occupational Hygienist, and it is conceivable that they together with the existing Occupational Hygienists could develop a formal course using people qualified in other fields to give instruction in their own subjects to a level considered desirable by the guiding body. It is believed that any formal post-graduate course would have only slender support until there is a different climate of opinion in the country and the first task must be to influence this climate of opinion. In short, every endeavour must be made to influence responsible people in industry, education, and the medical profession by short courses, discussion groups, articles in popular and technical journals, and other means of information. These should also be directed at the professions from which recruits will be obtained. It is felt that the British Occupational Hygiene Society should sponsor this initial part of the programme and that a cadre of selected members should devote any spare time they may have to this missionary work. Once there is a serious demand for occupational hygiene and a consciousness of its place in Industry, people will want to become Occupational Hygienists, and at the same time there will be a diminished tendency to refer matters connected with Occupational Hygiene to untrained scientists and engineers as part-time work. We cannot expect people to train themselves in occupational hygiene unless they are certain of finding jobs; similarly, we cannot expect jobs to be created for people who do not exist. We must expand our present small concentration of skilled workers to a point where it is effective from the point of view of publicity and education, both of which will stem from a high standard of practical work, by employing, if possible, first class young scientists on an apprenticeship basis supplemented by appropriate work in technical schools and colleges of further education. As the climate of opinion improves, more formal instruction might be provided on the "sandwich course" principles at colleges of advanced technology or universities might be induced to run post-graduate courses. Our ultimate aim should be for a degree course in the subject or, at least, having occupational hygiene as an elected subject in the final year of an honours course in Engineering. Anything less than a full academic year would not produce the standard of training desirable for a fully-qualified hygienist. We must be very

careful that any compromise we make between what is best and what is practicable does not result in an inferior article. A Diploma in Occupational Hygiene should have the same significance for everyone possessing it. An O.N.C., H.N.C. and Associateship course on a part-time basis at a technical school while working within the framework of occupational hygiene could be considered.

Once a national occupational hygiene service has been established the question of training will be easier and could be based on the system adopted by the Public Health Laboratory Service. The scientific staff would be recruited from young graduates who had been employed in Industry for not less than a year after passing their final examinations and their training would extend over a period of four years. Both medical and non-medical graduates would be eligible. The first year would be spent in a field laboratory learning routine methods and principles supplemented by education in the subjects in which they were deficient at technical schools and/or hospital laboratories. During the second year they would take the diploma course in occupational hygiene and in the third and fourth years they would be occupied at a main laboratory in further routine work, in field work and in research. The trainee would be paid on an increasing scale and the cost of courses and examinations would be paid by the service. In the third and fourth years they would take increasing responsibility, acting as substitutes in field units during holiday periods etc. The medical graduates in the second half would tend more to the toxicological, biochemical and physiological aspects of the work but in no sense should be excused doing routine environmental work. They would also carry out clinical work at hospitals, industrial medical centres and units of the M.R.C.

Undoubtedly, the main difficulty is the initial "break-through" and it is upon this we must concentrate our immediate aims and endeavours. These should be, firstly, to create a favourable climate of professional and public opinion, secondly, to train or get trained (in other countries, if necessary) first class scientists to form a suitable nucleus for expansion.

SHORT COURSES FOR EXISTING PERSONNEL AND OTHER INTERESTED PEOPLE

In order to establish a firm basis from which to work, short courses, lasting a week or a fortnight, at one of the universities or the London School of Hygiene, for example, might well be of value. These courses could be sponsored by the Society. A number of people have entered the sphere of Occupational Hygiene without knowing any of the basic principles of the subject; for example, where and how to sample, the necessary samples required to carry out an adequate survey, the significance and timing of biological tests, the variability of human beings, the basic principles of exhaust ventilation, statistical significance and many others. These courses would be comparable to the courses of similar length run for industrial medical officers and refresher courses for general practitioners.

ANCILLARY STAFF AND TECHNICIANS

In addition to the Occupational Hygienist, a national service would require scientists whose main work is in their own speciality; for example, analytical chemists, physicists and engineers. These would need to know the general principles of occupational hygiene to obtain a proper perspective. They would remain specialists

but their status would be no greater than that of the Occupational Hygienist in the same way as the specialist in medicine, theoretically at least, has no greater status than the general practitioner. Courses for them would be modified accordingly. The question of the industrial physician has already been discussed but there is no reason why he should not take the post-graduate course and obtain a diploma in occupational hygiene as an alternative to, or in addition to, his diploma in industrial health. If he does not wish to commit himself to that extent one of these shorter courses for specialists would be suitable. A shorter course would also be for librarians and clerical workers having to list and cross-reference articles in scientific publications.

Laboratory and field technicians would be trained on an apprenticeship basis supplemented by work at technical schools. Certificates and salary increases could be awarded for the various levels they attain on the same basis as hospital laboratory technicians are graded according to experience and whether they are members, associates, or fellows of the Institute of Medical Laboratory Technology.

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BOOK REVIEWS

Atmospheric Pollution in France

LE premier Congrès National organisé par l'Association Française de la Prévention de la Pollution Atmosphérique s'est réuni à Paris les 24 et 25 Novembre 1960. Les problèmes concernant la pollution due à la Radioactivité Atmosphérique et aux industries nucléaires n'ont pas été etudiés. Il ne nous est pas possible d'analyser les quarante cinq communications présentées; nous grouperons en trois catégories celles dont les textes sont actuellement en notre possession.

POINT DE VUE DE L'HYGIENISTE

Pour M. Policard, les suies provenant des combustions incomplètes des produits pétroliers peuvent être dangereuses, ainsi que les poussières de quartz, tandis que les poussières ferrugineuses et calcaires sont dépourvues de nocivité, celles qui renferment du plomb étant trop peu abondantes pour constituer un danger réel. M. HETTCHE indique les résultats d'études analogues en Allemagne, M. TRUHAUT discute les risques liés à l'éventualité de dépots sur les aliments, et M. WICHNIEWSKY estime que les dangers attribués aux gaz d'échappements des automobiles sont illusoires.

Les dégats produits par la pollution sur les végétaux sont examinés par M.M. BOSSAVY et JACQMON, tandis que M. RICHARD décrit les dégradations causées aux habitations.

MÉTHODES DE DOSAGE DE LA POLLUTION

On trouve les communications suivantes: technique et séparation des particules ultrafines par précipitation électrique (M. CHALLANDE), description de l'appareillage et des techniques de prélèvement utilisés dans les laboratoires d'hygiène de la ville de Paris (M. BRESSION, communication avec film), et en Allemagne (M. MELDAU); et enfin une méthode de dosage des produits présents dans les fumées de cigarette.

EVALUATION DE LA POLLUTION ATMOSPHÉRIQUE

D'abord dans les grandes villes: Paris (Origine et bilan des émissions de gaz carbonique, anhydride sulfureux et fumées dans le département de la Seine par MM. BESSON, Coin et Pelletier), Banlieue Parisienne (MM. MOUREU, CHOVIN, TRUFFERT et LEBBE), Lisbonne (MM. NORAES, QUINTAMILHA et MANTAS) et MILAN (M. ZURLO). Vient ensuite (MM. MARTIN et MAES) une comparaison entre la pollution dans différentes régions (rurale, résidentielle, rurale dans laquelle on a implanté une centrale thermique, et centre ferroviaire et métallurgique) puis des études de la pollution en fonction de la topographie (M. BAPSERES), de l'importance à la source d'émission (MM. MARTIN et MAES), une étude spéciale concernant la diffusion des fumées provenant des moteurs Diesel (M. WILLIAMS), et enfin une étude de la diffusion des aérosols dans l'atmosphère, faite d'ailleurs en vue d'expériences sur la pluie provoquée (M. VADOT).

LUTTE CONTRE LA POLLUTION ATMOSPHÉRIQUE

Diverses solutions sont proposées, basées sur des améliorations techniques de la combustion dans les foyers : Quelques aspects des moyens d'action contre la Pollution Atmosphérique grâce à l'utilisation rationnelle des combustibles (M. PERDON), Nouvelle réglementation d'utilisation des liquides inflammables (M. FOURNIER), Amélioration de la combustion dans les moteurs Diesel (M. TREGUIER), ou dans les moteurs à essence par l'emploi des catalyseurs (M. SCHACHNER), ou par l'emploi de dispositifs simples. (MM. DE BALSAC et SERRUYS), Amélioration des produits combustibles (désulfuration par M. HARISPE), combustibles appropriés (M. DE JERPHANION).

Ce quatrième groupe se termine par des descriptions de dispositifs permettant de supprimer ou d'atténuer l'émission de produits polluants : Dispositifs généraux (M. REVEL), Moyens techniques contre la pollution par les cheminées d'usine (M. MUHLRAD), Dispositions permettant d'éliminer la pollution par les Aciéries (M. SEPTIER), dans un Ensemble Sidérurgique (M. GAGNAIRE), dans les Chemins de Fer (M. MAINCENT), dans les Cimenteries (M. LECOEUR) et dans l'industrie Papetière (M. FINES). M. DE RETZ évalue la Pollution due actuellement aux Centrales Thermiques, et la compare à celle qui est imputable à d'autres souces nocives. Grâce aux dispositions prises, les Centrales Thermiques ne sont responsables en France que de 6 pour cent du total des poussières de charbon; d'aprés M. SPINART, l'ènergie Thermique est devenue deux fois moins polluante en moins de dix ans, et le deviendra encore moins lorsqu'on brulera des gaz naturels ou des Fuels saharien s à 5 pour cent de soufre.

<div align="right">J. BRICARD</div>

Scientific reports on industrial hygiene and occupational diseases in Czechoslovakia, 1959. Vol. 4.

THIS fourth bibliography published by the Institute of Industrial Hygiene and Occupational Diseases in Prague contains abstracts of papers published in 1959. The papers are by workers throughout Czechoslovakia and not only those working at the Institute. The bibliography consists of abstracts and summaries in English of 287 papers each of which is numbered so that readers interested in a particular article can quote the number when asking the Institute for a complete reprint. Papers are classified into four broad groups—occupational physiology, industrial hygiene, toxicology and industrial medicine (occupational diseases). It is difficult to convey the breadth of content of these papers but some attempt will be made on the basis of this classification.

OCCUPATIONAL PHYSIOLOGY

This section contains a study by Bena of working performance and fatigue allowances in coal unloading using measurements of calorie consumption. He has elaborated a table using these and calculated performance standards during a work period of eight hours, from which he estimates the maximum performance of an average labourer and optimum times of work and rest. Further papers examine changes in lung ventilation during training for football and hockey, the physiology of work in agriculture and forestry and the effect of working processes or inadequate

environment on the neuro-hormonal balance at various stages of a woman's life. Under the heading of physiology of the nervous system is much work that we would call psychiatric or psychomatic but this is inevitable when the approach to these subjects is essentially Pavlovian. As in similar material from the Soviet Union much of the work on maximum allowable concentrations of toxic substances is related to the threshold effect on the central nervous system as determined by the electro-encephalograph and relationships between stimulus and response of conditioned reflexes. Papers describe methods of measuring the latter.

INDUSTRIAL HYGIENE

In a summary of an address by Professor Letavet, of the U.S.S.R., there is emphasis on the need for a system of planned co-operation and co-ordination of the chief research problems in occupational medicine. These problems are enumerated as follows:

(1) Industrial toxicology—the clinical investigation and prevention of occupational diseases with a chemical aetiology.
(2) Pneumoconioses and their prevention.
(3) Physical factors in the industrial environment (including ionizing radiations) and their influence on the organism.
(4) The physiology of work.

Several papers deal with air conditioning, heating, ventilation and lighting. The technique of measuring air exchange by liberating small quantities of carbon monoxide and using an infra-red analyzer to measure its distribution is of interest. Much work is carried out on occupational hygiene in agriculture, a subject which is virtually non-existent in this country despite the fact that it is still the largest industry we possess. Papers on dust are scanty and contain little that is not known to workers in Great Britain and the U.S.A. Noise and vibration are dealt with in the same section and it is clear that some attempt is made to prevent noise rather than to just measure it. Forty-six abstracts deal with various problems of radiation covering local situations, population exposures, dosimetry and technical radiation protection.

TOXICOLOGY

Once again there is some emphasis on the use of the electro-encephalograph in the study of toxic substances. Chalupa, Synková and Sevčík show that EEG and experimental examination of memory are valuable ancillaries in ascertaining the degree of intoxication with substances such as carbon monoxide, trichlorethylene, methyl chloride and methyl bromide. Professor Teisinger makes the excellent point that it is not sufficient to merely measure atmospheric concentrations in workplaces but that it is also imperative to estimate absorption levels in exposed individuals; the levels of toxic substances or their metabolites in the blood or urine of exposed individuals being the indices. These levels should be correlated with the atmospheric concentrations. In the original paper the author describes exposure tests of this nature for lead, arsine, mercury, cadmium, carbon monoxide, carbon disulphide, trichlorethylene, benzene, toluene, aniline and nitrobenzene.

Oppl deals with the influence of air movement on the distribution and concentration of toxic substances. Correlation of concentration and air-flow was demonstrated by means of a two-dimensional isothermic model and the results of the work help in the correct selection of sampling points and the design of protective ventilation.

SKRAMOVSKY states that the choice of analytical method depends not only on the purpose of the investigation but also on the equipment in the laboratory performing it. This is often lost sight of when methods emanate from expensively equipped research units and University laboratories. He also makes a point, which is frequently overlooked, that it is necessary to decide on a suitable sampling method only in close co-operation with the physician who needs to know not only the total exposure to a toxic substance but the changes of concentration and their duration and has to be aware of the question of individual susceptibility in relation to these.

Amongst a number of toxicological papers dealing with different substances is one on the estimation of vanadium in urine with results relating to work people processing vanadium in the Ostrava region. The method used was based on the catalytic action of vanadium on the oxidation of an organic chromogen (identity not stated in the abstract) by potassium chlorate. Results showed a direct relationship between atmospheric concentration and urinary content.

The work on aliphatic organic compounds reveals little new apart from a polarographic estimation of methanol and ethanol in the presence of each other. Both alcohols are distilled through a layer of molten granular lead chromate whereby part of the methanol (3·4 per cent) is oxidized to formaldehyde and part of the ethanol (15·9 per cent) to acetaldehyde. The aldehydes are then estimated polarographically in 0·1N lithium hydroxide.

A further polarographic method, for estimating benzene in the presence of its homologues is described by VLASÁK. This was compared with the colour reaction of m-dinitrobenzene with methylethyl ketone in a pyridine medium which is well known to workers in this country. It was found that the error of method in both instances was ±5 per cent. Parallel samples estimated by both methods differ within the range of the experimental error. It is a pity that more details of the polarographic method are not given.

Three papers deal with the preservatives pentachlorphenol and sodium pentachlorophenolate describing toxicological studies on animals, their industrial use and estimation in the atmosphere, and the estimation of pentachlorophenol in biological material.

INDUSTRIAL MEDICINE

The general problems of industrial medicine are considered in papers on disabled persons, morbidity, the physical development of youth and the health care of women in industry. ŠTASTŃ describes new types of factory health centres which are being introduced by the Ministry of Health. The design depends on the size of the factory but is based on the need for comprehensive medical care by means of consultations with works medical officers and specialists. In addition to the usual facilities there are X-ray equipment, laboratory facilities, physiotherapy, dental surgery, a central registry and, in the case of large factories, an electrocardiograph.

The injurious effects of radiation and biological protection against it are dealt with in 33 papers and there is a section on general affections of the respiratory tract

and their effect on work. The section on pneumoconiosis and the one on its patho-genesis have little to add to what is known elsewhere and the same applies to the section on dermatology, although a long abstract on dermatosis in hop-pickers shows a nice appreciation of industrial medicine in relation to an occupational group which as far as the reviewer knows has never been studied in this country.

It is difficult to be more than superficial when dealing only with abstracts but the reviewer has had translations of a few original papers from Pracovni Lakarstvi and these, although selected, have been of a uniformly high standard. Many of the papers in this book of abstracts are obviously trite but so are countless papers published elsewhere. The value of examining the book lies in an appreciation of the amount and breadth of work being carried out in Czechoslovakia and a regret that the same drive and application of scientific method to matters of industrial health in this country is so sadly lacking. A further point which makes itself apparent is that the various disciplines, which here are tending to diverge—industrial medicine, environmental hygiene, ergonomics, psychology and basic research in relevant subjects—in Czechoslovakia are generally integrated into a single system of Indus-trial Health.

G. G. MATHEW

REPORT

Slough Industrial Health Service

Report by

P. J. R. CHALLEN

Physician-in-Charge, Occupational Hygiene Service 1959–1960

Editorial Note

We are printing below the annual report of the Occupational Hygiene Unit which is an integral, but self-accounting department of the Slough Industrial Health Service. This report, which forms part of the Annual Report of the Slough Service, is reprinted without alteration and shows the type of Industrial Hygiene Report that can be sent to managements. The number of member firms within the service is 205, employing 19,700 people.

The Occupational Hygiene Unit not only deals with firms within the service but, on a fee-paying basis, also handles problems from firms and authorities all over Britain. It is one of the very few units in this country which is prepared to tackle any industrial hygiene problem—J. R. GLOVER.

OCCUPATIONAL HYGIENE SERVICE

THE last twelve months have been characterized by intense efforts on the part of the staff and of the members of the advisory committee of the Service to make its facilities more widely known to industry and to professional colleagues. The financial position is unchanged, although income from consulting work is slowly but steadily increasing and we must be grateful to Slough Estates Limited for carrying the greater part of this burden. The Service has a wide gap to bridge before income equals expenditure and unless there is a rapid increase in the demand for investigations and advice by private industry it is unlikely that we shall be able to carry on with our present organization without some form of continued subsidy.

In an endeavour to pursue some of the ideas expressed in last year's report concerning the development of a pioneer regional occupational hygiene service every opportunity has been taken to interest those organizations mentioned in the report in the development and future of this Service. A meeting of the Medical Advisory Committee of the Industrial Health Service was held during the year and with its support an approach was made to a London Teaching Hospital and Medical School to see if the School would be interested in providing accommodation for an independent industrial hygiene unit. It was felt that advantages would accrue to each of the participants from such a unique association. The Medical School authorities found the proposal of some interest, in the light of their own ideas on the reorientation of medical teaching, and preliminary discussions are now in hand.

The future development of this Service has presented us with a number of conundrums in regard to organization and administration as well as finance. In June of this year a meeting was held at Slough to which many of the senior industrial

physicians of this country were invited. These problems were presented to them by the staff in order to obtain the benefit of their advice and criticism.

Because of the financial support provided by Slough Estates Limited it has been possible to increase the number of full-time staff and a senior medical laboratory technician and a secretary commenced duties with the Service on 2 April 1960. Previously we had managed with part-time assistance, but it was felt that we could not effectively expand our activities unless we did take this step forward. The technician will undertake our haematological studies, blood, urine and other biochemical tests and will give assistance to the chemist as well as helping to compile our reference library.

Altogether, the year has been one of steady, albeit undramatic, progress, with the exception of our research programme on noise which has now been inoperative for several months. For a number of reasons it became impossible for the Industrial Health Service to release the nursing sister we had trained in audiometry for her functions with this Service and it became necessary to think of a replacement. This consideration, together with the fact that the scope of the research was increasing, encouraged us to ask for a financial grant towards the cost of full-time technical assistance when presenting our Second Annual Report to the Medical Research Council. This request was acceded to but since its approval we have encountered difficulty in recruiting a suitable person for the appointment. However, the post has recently been filled and this technical assistant will be trained in the techniques of noise measurement as well as audiometry.

The work undertaken during the last twelve months is summarized in Tables A and B and, as a matter of interest, the total results are compared in Table C with those presented in the report for the year 1958–1959. It can be seen that the number of major investigations for firms outside the Slough area has risen to twenty-three and these investigations have taken place in industries situated in all regions of the country. The source of the enquiries from firms outside the Slough area is shown in Table D and it is gratifying to observe the number of requests which have come from industrial management and the Trades Unions; in previous years we were almost entirely dependent on the demand from industrial medical officers and nursing sisters. In addition to the increase in the number of investigations carried out for firms in other regions, there has been a definite tendency for the nature of these studies to be more complex thus demanding more time for their completion.

The number of major investigations carried out for Slough firms has also risen, together with a welcome increase in the number of occasions when they seek our advice at the design stage of a new process or department. This latter progress is most encouraging and it shows that there is a growing awareness on the part of member firms of the economic value of such advice at this stage and of their increasing understanding of the effect of environmental factors on health, safety, comfort and production efficiency.

Although air sampling and clinical study may have demonstrated at one time or another that the operations in a degreasing shop are safe, unless the situation is reviewed from time to time, changes in the process or its operation can occur which, in no time at all, will render it a hazardous one. A family practitioner consulted the Industrial Health Service concerning one of his patients whom he had been treating at home for two months and whose symptoms he thought might be

attributable to an occupational exposure. The patient had been operating a de-greasing tank for thirteen years without trouble; then, over a period of six months he developed severe symptoms of trichloroethylene intoxication. Shortly before he commenced to notice ill-effects his degreasing tank had been transferred to another location, where previously there had been a smaller unit, and the flow of work he had to handle greatly increased. The new location had poor general ventilation and no local exhaust ventilation system was provided for the degreasing tank. Air concentrations of trichloroethylene were found to be greatly in excess of the American permissible limit of 200 p.p.m. (parts per million) which is, in the opinion of many experts, too high a limit: and estimations of the trichloroacetic acid content of the urine of a substitute operator confirmed the high air concentrations. It is hoped to avoid such an occurrence in the future by instituting periodic estimations of the trichloroacetic acid or trichloroethanol content of the urine for all degreasing tank operators in member firms.

TABLE A. INVESTIGATIONS IN SLOUGH FACTORIES

Type	Investiga-tions No.	*Advice at design stage No.	*Advice on existing processes No.
CHEMICAL			
Acrylonitrile			1
Ammonia	1		
Benzene	2		
Epoxide Resin ..	1		
Fluorides		1	
Hexamine		1	
Ozone	1		
Phosphorous			1
Sulphur Hexafluoride		1	
Toluene	3		
Trichloroethylene ..	1		
Xylene	1		
Zinc	1		
DUSTS			
Asbestos	2		
Iron oxide		1	
LIGHTING	1	4	
THERMAL		2	
NOISE	2†	1	
IONIZING RADIATION ..			1
TOTAL	16	11	3

* Advice includes advice on the design of ventilation systems.
† Excluding firms taking part in noise research.

Noise is not one of the hazards which is usually associated with welding processes, but this is a subject in which we have become interested and we have had the

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opportunity of investigating the noise from two such processes, and of noting a
noise hazard during metal spraying which is a process allied to welding.

TABLE B. INVESTIGATIONS IN FACTORIES OUTSIDE SLOUGH

Type	Investigations No.	*Advice at design stage No.	*Advice on existing processes No.
CHEMICAL			
Acids	1		
Benzene	1		
Cosmetic industry ..	1		
Epoxide resin ..	1		
Lead	3		
Oil mist	3		
Perchloroethylene ..	1		
Printing and lacquering			1
Spray painting ..	1		
Trichloroethylene ..			1
Zinc	1		
DUSTS			
Asbestos	1		
Paper	1		
Silica	1		
THERMAL	1	1	
NOISE	6		
TOTAL	23	1	2

* Advice includes advice on the design of ventilation systems.

TABLE C. COMPARISON OF INVESTIGATIONS CARRIED OUT
1958–1959 AND 1959–1960

	Investigations No.	Advice at design stage No.	Advice on existing processes No.
SLOUGH			
1958–1959	10*	7	12
1959–1960	16*	11	3
OUTSIDE SLOUGH			
1958–1959	14	5	1
1959–1960	23	1	2

* Excluding firms taking part in noise research.

In one firm octave band analysis of the noise during butt welding showed that the
level of noise substantially exceeded the British damage risk criterion, see Fig. 1.
Audiometric examination of the two employees exposed to the noise gave evidence

that one had a high-tone hearing loss, attributable to acoustic trauma, and the other had a predominantly low-tone loss, due to otosclerosis, a disease of the middle ear which is amenable to operative treatment and which may have given this employee some protection against the effects of noise, see Fig. 2. It is interesting to note that in this instance the firm had already consulted acoustical engineers and the welding machine was fitted with silencers on the air discharge nozzles prior to our investigation. The employees are now supplied with ear muffs and are given annual audiometric tests. The value of ear plugs and ear muffs in reducing the noise exposure of the wearer is graphically shown in Fig. 1.
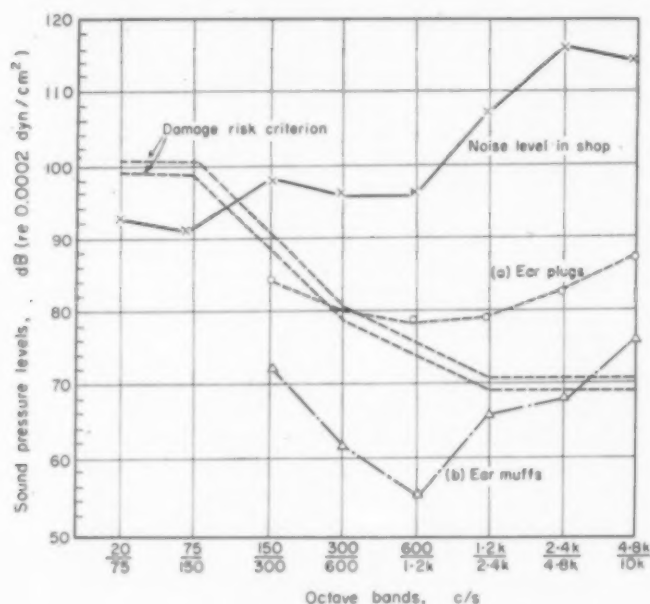
FIG. 1

TABLE D. SOURCE OF ENQUIRIES FROM FIRMS OUTSIDE SLOUGH

Type	No. of enquiries
Managements (including personnel, welfare and safety)	9
Industrial Medical Officers	8
Trades Unions	4
Industrial Nursing Sisters	2
Consulting Ventilating Engineers	2
Medical Officers of Health	1
TOTAL	.. 26
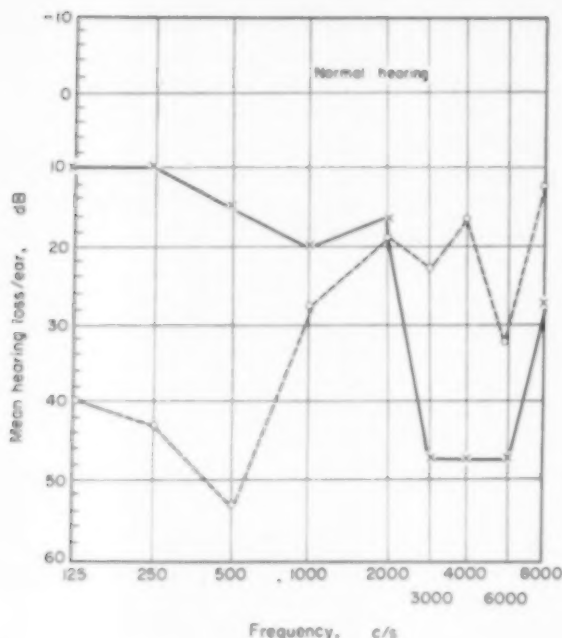
Fig. 2

Welding has made rapid technological progress during the last ten years and a new process, the plasma jet, is now under development in this country. The principle of this process is that an intense jet of electrons and ionized gas particles is forced to issue through a very narrow orifice. The jet is formed by the passage of a gas such as argon, helium or hydrogen through an electric arc which is struck between two electrodes in a confined space; at the same time the gas is heated to arc temperature. The emitted plasma flame can reach a temperature of 60,000 °F and the process is now seen to have great potentialities in welding and allied fields. A primitive plasma jet device was devised many years ago but the modern plasma torch was introduced to industry in the U.S.A. in 1955 for the cutting of aluminium. This torch can be used for cutting and welding metals, for metal spraying and when mounted in a wind tunnel reproduces the conditions that a missile would encounter when re-entering the earth's atmosphere. Nose cone materials and designs can thus be tested under simulated operating conditions. Measurements of the noise from this process, together with hearing tests conducted on a number of volunteers who exposed themselves to the noise for a period of hours have demonstrated that the process presents a hazard to hearing. We are also studying the air contamination produced by this process and we are at present carrying out air sampling for ozone and nitrous oxides.

There appears to be a wave of interest in noise as a community and industrial problem at the present time. A number of studies we have carried out in industries outside the Slough area have elicited the presence of a hazard to hearing and considerable interference by the noise with communication by speech. In some instances

there was an indication that the noise, because of its intensity and frequency characteristics, was causing irritation and minor psychological symptoms in some of the employees and that it could be blamed as a contributory factor in a high labour turnover. We were able to demonstrate in one firm, in which there was a noise problem in a number of workshops, that the major reorganization of the factory which management was planning would aggravate an already severe hazard. A major obstacle discouraging some firms from having their noisy processes investigated is a suspicion, which is well-founded, that reduction or suppression of noise at source is in many instances difficult and costly, if not impossible to achieve. Excluding personal protective measures, there are many engineering methods for reducing noise in a workshop even though they may not be applied at source, but the value of these in any set situation is not often assessed in terms of employee health and safety. There is certainly a great need for fundamental research on methods of suppression of noise at source and on machine design with this particular objective in view. In our experience punch press and automatic machine shops can be productive of dangerous levels of noise, and because they are ubiquitous in modern industry, an indeterminable but significant number of working men must be exposed to a hazard.

Therefore, these two processes seemed suitable ones for a research project, and with this idea in mind the physician and engineer visited the Noise Control Section of the National Engineering Laboratory, Glasgow, to find out if it were feasible for the two organizations to collaborate on such a project. A great interest was shown by the staff of the Noise Control Section, who are already investigating the sources of noise in machines. It would appear difficult for the National Engineering Laboratory to collaborate with us at present because of their other commitments and limited staff available. However, it would be possible for them to undertake additional work provided the necessary financial support was forthcoming.

Much of the work of any industrial hygiene laboratory is in relation to toxic materials which are in common use in industry, even though the industrial situations in which they are used have an unbelievable diversity. However, new problems are always arising and this year we received a number of requests to investigate processes involving the operators in exposure to mineral oil mists in the working atmosphere. In the process of developing methods for air sampling and analysis we discovered that other workers in the country and in the U.S.A. were engaged on similar studies. Indeed, we must acknowledge our thanks to Mr. E. King of the Department for Research in Industrial Medicine at the London Hospital, for considerable assistance and advice in developing our sampling and analytical methods. There is, as yet, no agreement amongst industrial physicians and hygienists concerning a safe permissible limit for mineral oil mists, and in setting such a limit consideration may have to be given to the carcinogenic properties of some of the constituents of the oils. The determination of carcinogenic substances in mineral oils is not an easy matter and it is not a subject for research in laboratories such as ours which are primarily organized to give a day to day service to industry.

The physician and the engineer continue to give instruction, in the lecture room and in the field, to post-graduate students from the London School of Hygiene and Tropical Medicine, the Royal Institute of Public Health and Hygiene and the Royal College of Nursing. In addition, they have taken part in various conferences for such

bodies as the Royal Society for the Prevention of Accidents, the Industrial Welfare Society, the Institution of Industrial Safety Engineers, the Institute of Welding and at a number of technical colleges. They have both served on committees for the British Occupational Hygiene Society and the Institute of Welding.

Each year we receive annual reports from a number of industrial hygiene divisions and laboratories in the U.S.A. and Canada and the record of the amount of work carried out by these organizations—with a considerable staff—emphasises how small a contribution this occupational hygiene service is making to the need for industrial hygiene of industry in this country—even if this need is not appreciated by industry. The Bureau of Industrial Hygiene in the Detroit Department of Health "has the primary objective of stimulating all employers to so conduct work operations that the health of workers and nearby residents will not be impaired."* With these words Dr. William G. Frederick, the able and well-known Director of the Bureau, introduces his 1959 Annual Report, and he continues in the following vein: "Attention is primarily directed to the numerous work places which are too small to support their own industrial health and occupational disease prevention programmes. Four thousand seven hundred and ninety-four investigations were made in 2,313 of Detroit's 42,250 work places. Two thousand four hundred and sixty-six plant improvements were required which directly benefited 89,065 employees. Of Detroit's 815,000 workers, 290,474 were employed in establishments inspected during 1959. Over 10,000 analyses and measurements were made to aid in establishing the healthfulness of work environments. Specific requests for services from employers, employees and other governmental agencies numbered 1,480."

Where is there a working community of this size in this country which can boast of such a preventive industrial health service? The answer, quite briefly, is that there is none. This is a measure of our lag in progress in this field, not to mention the lack of trained personnel and of modern equipment, provided in American industrial hygiene laboratories.

PUBLICATIONS

HICKISH, D. E. (1960) Sensations of warmth and freshness of workers in light industry in summer. *Ann. Occup. Hyg.* 1, 271—279.
HICKISH, D. E. and CHALLEN, P. J. R. (1960) A study of noise in a circular-saw shop and its effect on hearing. *Ann. Occup. Hyg.* 2, 133—140.

* Bureau of Industrial Hygiene, Detroit Department of Health (1959), Annual Report.

NOTES

The control of noise

A three-day conference on this subject is being held at the National Physical Laboratory, Teddington, on the 26th to 28th June, 1961. It is being promoted by the National Physical Laboratory together with the Building Research Station and the National Engineering Laboratory of the Department of Scientific and Industrial Research. Problems discussed include noise control, the nature of noise from various sources, insulation, factory noise and industrial deafness, amenity problems, aircraft and motor vehicles, and legislation.

The papers are being precirculated and the proceedings will be published by Her Majesty's Stationery Office.

The Middlesex Hospital Medical School, London, W.1. Department of Physics as Applied to Medicine

Full-time Day Course in Radiation Hazards and Safety

A course, extending over four weeks, will commence on Monday, 16 October 1961, and will provide an introduction to the subject suitable for medical, engineering, chemical and other professional workers whose duties require an overall appreciation of the problems involved in maintaining radiological safety in the utilization of radiations and radioactivity in industry and medicine.

The course will consist of lectures, demonstrations and practical work dealing with:

Radiation Physics
Radiation Chemistry and Biology
Applications of Radiation in Industry and Medicine
Radiation Effects on Humans
Radiological Protection
Health Problems arising in the Nuclear Energy Industry

Applications for admission to the course should be made to the Secretary, Department of Physics as Applied to Medicine, Middlesex Hospital Medical School, London, W.1, from whom further details of the course can also be obtained. The fee for the course will be £40.

Concentrations (p.p.m.) of oxides of nitrogen and exposure time (minutes) causing different mortalities (results from 15 authors)

	Concentration (p.p.m.)	Where 100 per cent of animals died:						Where less than 100 per cent of animals died:						Where no deaths were reported:					
		Exposure time (min)	Animal species	Source of fumes	Lung damage	Met-haemoglobin	Mortality in animals	Exposure time (min)	Animal species	Source of fumes	Lung damage	Met-haemoglobin	Mortality in animals	Exposure time (min)	Animals species	Source of fumes	Lung damage	Met-haemoglobin	Mortality in animals
No effects	8·5													240	Rt	NO_2	−		0/6
	16													240	Rt	NA			0/10
	21													240	Rt	NO_2			0/6
	23													240	Rt	NA			0/10
	30													180	G	NO_2	−		0/3
	33													?240	Rt	NA	−		0
	34·5													240	Rt	NO_2	−		0/6
Lung damage	42													240	Rt	NO_2	+		0/6
	48													240	Rt	NA			0/6
Deaths reported	53							240	Rt	NO_2	+		1/6						
	55							150	*	NO_2	?+		2/12						
	58							240	Rt	NO_2	?+		1/10						
	62							240	Rt	NA	+		1/6						
	65							240	Rt	NO_2	+		5/6						
	68							240	Rt	NO_2	+		1/10	240	Rt	NO_2			0/6
	72							240	Rt	NA	+		18/22	180	Rb, C	OxNO			0/2
	74																		
	75	240	Rt	NA	+		10/10												
	79							240	Rt	NO_2	+		3/6						
	89							240	Rt	NO_2	+		3/10						
	93							240	Rt	NA	+		2/20						
	95							240	Rt	NO_2	+		6/10						
								157	C	OxNO	+		1/2						
	96							240	Rt	NO_2	+		8/10						
								318	*	NO_2	?+	+	14/19						
	100	58	C	CAF	−	+	2/2	1074	G	CAF	+	−	3/5						
		70	M	CAF	−	+	3/3												
		460	Rt	CAF	+	+	3/3												
		960	Rb	CAF	+	−	1/1												
	108							240	Rt	NA	+		5/10	420	C	OxNO			0/1
	116													360	C	OxNO			0/1
	125																		
	126	150	M	UCAF	−	+	2/2	1250	G	UCAF	+	−	3/4						
		480	Rt	UCAF	+	+	4/4												
		1320	Rb	UCAF	+	−	1/1												
	128							240	Rt	NA	+		2/10						
	129							240	Rt	NO_2	+		9/10						
	148							240	Rt	NA	+		3/10						
	150							90	*	NO_2	+	+	9/13						
	162	240	Rt	NO_2	+		10/10												
	163							240	Rt	NA	+		7/10	180	Rb	UCAF			0/1
	177							240	Rt	NA	+		8/10	75	Rb	OxNO			0/1
	200	240	Rt	NA	+		10/10	75	*	NO_2	+	+	12/13	62	C	OxNO			0/1
	205													73	C	OxNO			0/3
	215																		
	218	255	C	OxNO	+	?+	1/1												
	226	330	C	OxNO	+	−	1/1							90	C	OxNO			0/2
	230																		
	234	424	C	OxNO	+	−	1/1							80	C	OxNO			0/3
	252	240	Rt	NA	+		10/10							60	Rb	OxNO	+	−	0/1
	260													110	C	OxNO			
	287							15	Rt	NO_2	+		7/10						
	287																		
	343	209	C	OxNO	+	+	2/2	80	C	OxNO	+	+	2/3						
	350																		
	374	120	C	OxNO	+	+	1/1												
	390	72	C	OxNO	+	+	1/1												
	390	105	Rb	OxNO			1/1	58	*	NO_2	+	+	12/13						
	400																		
	405							77	C	OxNO	+	−	2/3						
	413	47	C	OxNO			1/1												
	413	100	Rb	OxNO	+	−	1/1												
	460	79	C	OxNO	+	−	3/3												
	500	30	−	NO_2	?+														
	532	30	Rb, Rt, G	$?NO_2$															
	597							5	Rt	NO_2			3/10						
	600							32	*	NO_2	+	+	13/14						
	628	30	Rt	NO_2			10/10												
	649	15	Rt	NO_2			10/10												
	695	59	C	OxNO	+	+	2/2												
	731							2	Rt	NO_2			1/10						
	800	29	*	NO_2	+	+	13/13							2	Rt	NO_2			0/10
	824																		
	888							5	Rt	NO_2			3/10						
	1000	19	*	NO_2	+	+	9/9												

NOTES

(i) Concentrations are means where a range was given.
(ii) Exposure times are means for the group.
(iii) Animal species: Rt = Rat; C = Cat; Rb = Rabbit; G = Guinea-pig; M = Mouse; * = All 5 species.
(iv) In column headed "Lung damage" and "Methaemoglobin": + = presence reported; − = absence reported.
(v) In column headed "Source of fumes": CAF = Carbon Arc Fumes; UCAF = Unfiltered Carbon Arc Fumes; NA = nitric acid fumes; OxNO = Oxidized Nitric Oxide; NO_2 = nitrogen dioxide.

APPENDIX B. PROLONGED EXPOSURES OF ANIMALS TO OXIDES OF NITROGEN

Concentrations (p.p.m.) of oxides of nitrogen and exposure time (hours) causing different mortalities (results from 8 authors)

	Concentration (p.p.m.)	Where 100 per cent of animals died:									Where less than 100 per cent of animals died:									Where no deaths were reported:								
		Duration of each exposure hr/day	Total exposure in weeks	Total duration of exposure hr	No. of times exposed	Animal species	Lung damage	Met-haemo-globin	Mortality of animals	Loss of weight	Duration of each exposure hr/day	Total exposure in weeks	Total duration of exposure hr	No. of times exposed	Animal species	Lung damage	Met-haemo-globin	Mortality of animals	Loss of weight	Duration of each exposure hr/day	Total exposure in weeks	Total duration of exposure hr	No. of times exposed	Animal species	Lung damage	Met-haemo-globin	Mortality of animals	Loss of weight
No effects	2·9																			4	7	146	37	Rt	−		0/50	
	3·4																			4	22	449	112	M	−		0/30	
	3·8																			4	23	472	118	Rt	−		0/40	
	4·3																			4	19	384	96	G	−		0/10	
Lung damage	5																			22	2·5	400	18	G	+	?	0	
	9·3																			4	1·5	40	10	Rt	+		0/10	
	10																			4	2	64	16	Rt	−		0/14	
	10																			22	2·5	400	18	G	+	?	0	
	10·1																			4	3·5	96	24	Rt	+		0/10	
	12·3																			4	2	56	14	Rt	+		0/10	
	13										6	9	*276	46	Rt		+	3/24	+	6	9	*276	46	Rb			0/16	+
	14·3																			4	3·5	96	24	Rt	+		0/10	
	24																			6	7	258	43	Rt		+	0	+
	24																			6	7·5	270	45	Rb		+	0	+
Deaths recorded	29										5	7·5	190	38	Rb	?+		2/17	+	5	7·5	190	38	Rt	−		0/24	
	33																			4	3	80	20	Rt	−		0/3	
	33																			5	4	100	20	Rt	+		0/12	+
	33																			5	4	100	20	Rb	−		0/12	+
	40										5	7	†170	34	Rb	+		3/11	+									
	40										5	7	†170	34	Rt	+		10/24	+									
	50																			24	4	700	1	Rb, G	+		0/7	+
	70																			6	0·5	18	3	Rt		+	0	+
	77										5	6	125	25	Rt	+		3/24	+									
	77										5	6	125	25	Rb	+		3/12	+									
	107	4	24	408	102	Rt	+		10/10		4	29	688	172	G	+		8/12	+									
	115	1	38	228	228	Rt	+		5/5																			
	115	4	16	384	96	Rt	+	+	9/9	+	4	32	768	192	G	+	−	11/12	+	1	43	300	300	G	−		0/5	
	125	4	17	408	102	Rt	+	+	10/10		4	33	800	200	G	+	−	11/12	+									

NOTES

    (i) Concentrations are means where a range was given.

    (ii) Exposure times are means where a range was given.

    (iii) In columns headed "Lung damage, Methaemoglobin and Loss of weight": + = presence reported; − = absence reported.

    (iv) In columns headed "Animal species": Rt = Rat; Rb = Rabbit; G = Guinea-pig; M = Mouse.

    (v) *At high temperature—30·31·7 °C.

    †At high temperature—31·7–40 °C.